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Procedia Engineering00 (2015) 000–000

Procedia Engineering

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6th BSME International Conference on Thermal Engineering (ICTE 2014)

# Performance of an Electricity-Generating Cooking Stove with Pressurized Kerosene Burner

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**Abstract**

A clean-burning cooking stove that also generates electricity (The Score-Stove™) was modified to enable evaluations to take place in 3 regions of Bangladesh. Using the principle of thermo-acoustics to generate electricity it can supply power for applications such as - LED lighting, mobile phone charging and radios particularly in rural areas without grid electricity. After assessing the needs of the rural communities through a survey, tea-stalls and small restaurants owners were identified as people with the most potential of using the Stove in Bangladesh. The Bangladesh University of Engineering and Technology ((BUET) modified a Score-Stove to use both wood and a pressurised kerosene burner of a design that is widely used for cooking in rural areas of Bangladesh. The design was adapted to meet performance needs such as: heating rate, cooking efficiency, energy distribution, electric power generation, exhaust emissions and time taken to boil water using standardised water boiling tests. Performance was also compared with conventional (non-electrically generating) stoves that use a pressurised kerosene burner. A stove suitable to be demonstrated was developed to obtain feedback from some end-users for evaluation. Effects of the technical changes to the stove required for field trials and laboratory experimental results are presented. Technical deficiencies are documented and recommendations for improvements and future research in order to obtain wider end-user acceptance are made.


Peer-review under responsibility of organizing committee of the 6th BSME International Conference on Thermal Engineering (ICTE 2014).

*Keywords:* Score-Stove; Thermo-acoustics; Clean cooking stove; Small-scale power; Kerosene burner

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## 1. Introduction

Over three billion people around the world, particularly in Sub-Saharan Africa, Indian subcontinent and South America cook an open fire stoves, and 1.4 billion are deprived of grid electricity. Inefficient burning causes thousands of tons of carbon emission as well as serious health hazards to the users, which causes almost four million people to die prematurely each year due to household air pollution (HAP) [1]. The Lancet [2] states that household air pollution is the leading risk factor for premature deaths in south Asia.

Despite the high death rates, the problem continues to be intractable for a variety of reasons [3]. The World Bank [4] states "… In short, many approaches to introducing improved stoves have been tried, with some successes and many failures…". There is a growing body of opinion that more radical approaches are needed [5]. Riley [6] argues that the addition of electrical generation to cooking stoves increases the affordability and hence social acceptance of clean cooking. Studies in Malawi [7] using thermo-electric technology have made some progress, although the power produced is low, about 3 Watts of electricity. Another thermo-electric stove that is commercially available for use in developed countries and has had trials in Laos, is the Biolite [8] that produces about 2 to 3W. It only take small pieces of wood and so is thought unsuitable for areas where cut wood is about 50 to 70 cm long [9].

In Bangladesh, the per capita energy consumption of 321 kWh is one of the lowest in the world [10], [11] a fact recognised by the Bangladeshi government which is committed to improving the situation. Recent developments in thermo-acoustic technology have shown potential to provide solutions to the problems set out above [12], [13], [14], [15]. This paper describes the use in Bangladesh of the Score-StoveTM [5] that incorporates the thermoacoustic principle to generate electricity whilst cooking by converting excess thermal energy into electrical energy before releasing waste energy to the atmosphere. With the use of a chimney and proper combustion of air-fuel the stove can provide a non-smoky and healthier environment inside the kitchen.

**Nomenclature**

| | | | | | |
|---|---|---|---|---|---|
| AHX | ambient heat exchanger | PAB | practical action Bangladesh | TBT | thermal buffer tube |
| HHX | hot heat exchanger | PVC | poly vinyl chloride | SS | stainless steel |
| HAP | household air pollution | TAE | thermo-acoustic engine | WBT | water boiling test |

## 2. Background and working principle

Byron Higgins (1777) first documented the thermoacoustic phenomenon [16]. A century later Lord Rayleigh explained the phenomenon qualitatively [18], in the 1960s'. From then until the 1990's others progressed understanding [17,18] until progress became much more rapid through the theoretical work of Swift [19] at Los Alamos laboratories [21] and the practical realisations of deBlok from Aster [22]. Fig 1 below shows the basic components of a dual full wavelength, looped tube travelling wave engine as used in the Score-Stove™.

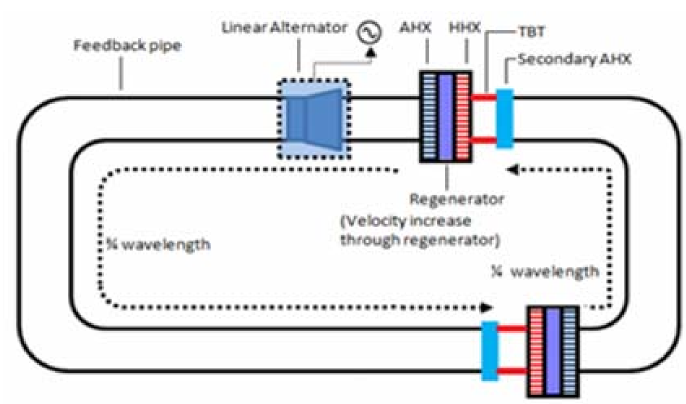


Fig. 1. Functional diagram of SCORE-Stove.

In a thermoacoustic engine, heat is supplied from a source to a gas (air in Score-Stove) via the hot heat exchanger (HHX), heat is removed via the ambient heat exchanger (AHX) and the gas undergoes repetitive thermal expansion and rarefaction to produce acoustic energy. Between the HHX and AHX is a porous material called a regenerator, with a temperature gradient across it, to sustain a resonant acoustic wave and a linear alternator within the closed loop converts the acoustic wave into electricity. In the field trial Score-Stove design the linear alternator was implemented using a low-cost loudspeaker working in reverse.

## 3. Design of Field Survey

### *3.1 Methodology*

Work in rural Nepal and Uganda [23] has shown that low cost is essential for acceptability by the local people. To meet the low cost target, the Score-Stove requires much more research and is currently too expensive for single household use, although work on affordability [6] and recent trials in Nepal by Kathmandu University [24] have shown that the cost targets are not as onerous as first thought. For the BUET research the objective was to find a solution that was less cost sensitive, more in tune with Bangladesh cooking habits and so could be implemented more quickly.  Small tea shops were identified as highly potential users as stall owners typically were found to use small cookers running on kerosene, briquette of sawdust or biomass fuels for long hours. Additionally, they often have to buy electricity from a nearby stall that has a petrol/diesel-driven generator.

Therefore a Score-Stove was modified for use in Bangladesh and tested under laboratory conditions to ensure it was safe and suitable for later field trials undertaken with a field survey (yet to be published) with the help of Practical Action Bangladesh (PAB). This paper describes the preliminary work required for the later field trials.

### *3.2 Proposed implementation*

Fig. 2. Field survey for identification of applications and potential user

Larger shops tend to use pressurised kerosene burners but smaller ones use gravity feed. Often two pots are used side by side, one for boiling and the other for pre-heating even though some burners had limited capacity for doing this. A typical tea stall size is 3 x 5 m, which could spare only 0.5 x 1 m for the stove, imposing restriction on its acceptable physical size. Road side restaurants were also identified as another source of potential users of Score-Stove. They have stronger burners and longer operational hours. Both pressurised kerosene and larger wood burners were found to be in use. However their electrical power requirement was in the order of one kilowatt so they often have a mains electric supply. These premises would not gain enough benefit from a Score-Stove. Fig 2 shows picture of the more potential applications. The right hand-side of the figure is typical of the pressurised kerosene burners used by the traders; two burners can be seen.

## 4. Construction and Modification of Score-Stove

In order to make the Score-Stove useful to rural people, it was designed and constructed in such a way so that it could be run using kerosene, wood, briquette of sawdust or other biomass as fuel. Flexibility of usage of fuel was considered a key requirement for the targeted remote rural areas. BUET constructed the modified frame in two parts for ease of transportability with two mild steel components bolted together. A 45 degree inclined metal frame was used for supporting the TAE, and another part of the frame housed the cooking pots and chimney for removal of exhaust gas. This arrangement is adaptable for a regular kerosene stove or alternatively a wood/biomass burner placed below the TAE.

Hot gases from the burner pass through a BUET designed combustion chamber passage over the HHX then across the cooking pots. Combustion chamber and gas passages are made of stainless steel which has higher resistance to corrosion. Stainless steel sheets are bolted to the second metal frame and at the centre of the sheets are holes to house cooking or tea pots. After passing under the cooking pot the hot gas moves up the chimney and exhausted outside. Combustion chamber and cooking hob are insulated with a combination of rock and ceramic wool of 75 mm thickness to minimise heat loss. The top surface of the hob was made of stainless steel so that corrosion that is common due to the water from cooking could be avoided.

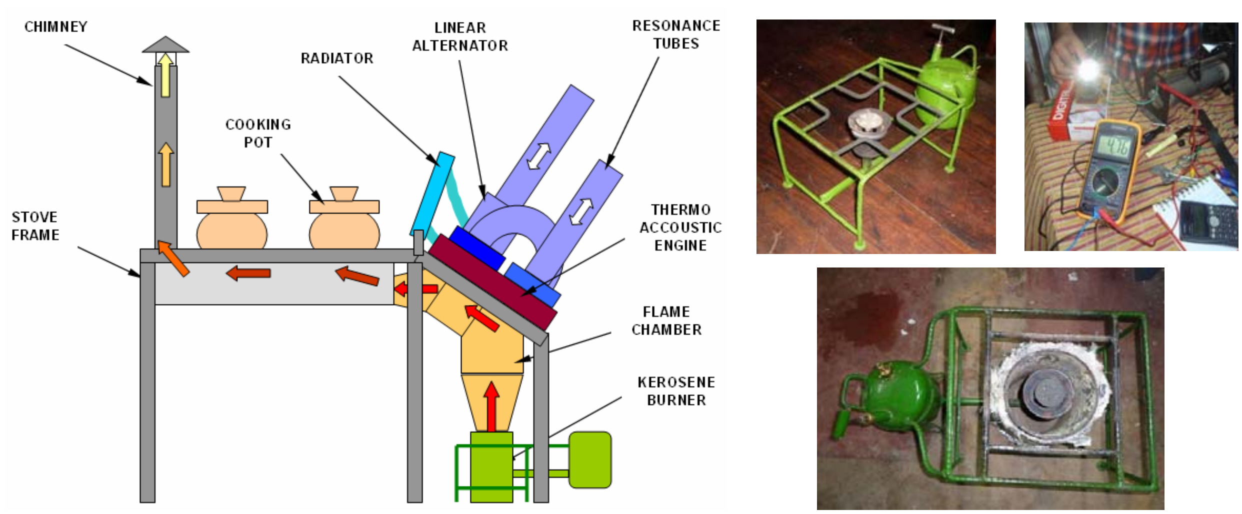


Fig. 3. Score-Stove schematic showing components and flow path of flue gas and typical(top) and modified(bottom) kerosene burner on the right.

To generate the travelling wave, a closed loop of PVC pipes was used with several joints, as shown on the right of Fig 4. For trials outside the laboratory, a car radiator was used for cooling the AHX in a closed loop that used the thermo-siphon effect to circulate the water and natural air convection to cool the radiator and alternatively continuous flow from the mains water for experimental work. A loudspeaker used in reverse converts acoustic energy into electrical energy. Fig 3 shows the schematic diagram of the two frames and a more detailed description of the TAE operation can be found in this reference [25].

For the kerosene option, testing showed that although the flame temperature is almost 1000°C at the burner, the temperature quickly drops as the flame moves away from the burner core due to excess air ingress around the burner; hence the flame burns with a lean air-fuel ratio giving good clean combustion but lower flame temperature. For correct operation the HHX needs to be over 700°C to start thermoacoustic resonance.

A number of options were tried to reduce the excess air and finally a cylindrical replaceable metal shielding with insulation on the outer side as the simplest modification for controlling excess air flow was incorporated. Use of the shield reduced excess air flow and raised the flue gas temperature to the required level. Fig 3 shows a normal kerosene stove on the right at the top and the modified kerosene stove with cylindrical shield at the bottom. The wood option was similar to the kerosene option, but with a BUET designed combustion chamber in place of the kerosene burner, as shown on the left of Fig 4.

Fig. 4. In the wood burning version of Score-Stove (left) the kerosene burner (right) is replaced by a wood burning section.

## 5. Laboratory testing

Stove performance was tested during typical water boiling tests (WBT) and the heat input rate was calculated from the gravimetric measurement of the fuel consumption rate and the lower heating value. Temperatures of the flue gas, TAE HHX and AHX were recorded using K-type thermocouples and a National Instruments compact data acquisition system. Mass flow rate and temperatures of the cooling water and the exhaust leaving the chimney were recorded to estimate the heat losses. The electric power voltage and current produced from the linear actuator was measured using a watt-metre with either LED lights or a variable resistance as a load in order to check the sensitivity at different loads (fig 3 right top). The major parameters recorded during the laboratory water boiling test are given in Table 1. Field trials later demonstrated the Score-Stove in a number of locations in rural Bangladesh.

Table 1. Performance parameters of Score-Stove in a WBT test

| **Test Type** | **WBT** |
|---|---|
| **Parameters** | **Result** |
| Amount of water | 2 kg water in each of two pots |
| Temperature | From 26°C room temperature to 80°C |
| Fuel | Kerosene |
| Resonance initiation (onset) | 11 min 17 seconds after start-up, Frequency: 64 Hz |
| Power output | About 3.5 watts (lighting 2 LED lamps) |
| Maximum current | 0.7 Amp at 5 volts |
| Fuel consumed | 0.36 Lit/hr |
| Temp of TAE hot-end | 700°C |
| Temp at exhaust | 175°C |
| Exhaust condition | clear exhaust, almost invisible |

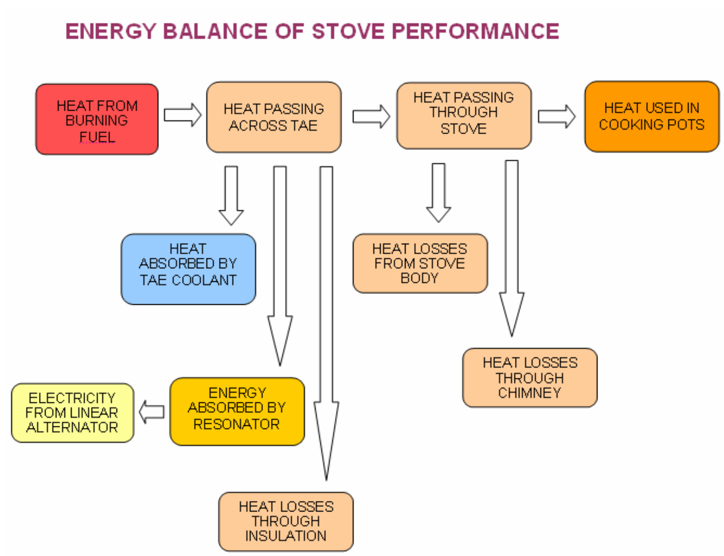


Fig. 5. Flow diagram of heat balance components

For the WBT, two identical water pots each filled with 2 litres of water were placed on the stove. Resonance started after about 11 minutes of heating at about 64 Hz and the lights came on within 12 minutes. The first pot reached a temperature of 80°C after about 39 minutes, while the water in the second pot reached 64°C. It took 15 minutes more to get another pot of hot water at 80°C if the preheated water of the second pot was used to replace the water in the first pot. The burner was needed to be kept on, for the whole time. Resonance and lights would keep on for about 3 minutes when the burner is extinguished due to thermal storage in the system. During testing a number of issues were found that need to be addressed:

- TAE performance was robust as long the air in the resonance tubes was well sealed
- Heat was lost through the stove body (despite the insulation) and it reached about 60°C before stabilising
- The heating rate of the burner was found to vary from run to run, within an order of ±10%. Variation of vapour pressure with tank body temperature and poor piston finishing were mainly responsible for such variations
- With the pressurised kerosene burner, reduced air flow increased the flame temperature (to make the TAE more efficient) caused more heat to be conducted to the fuel pipe which increased kerosene temperature. This resulted in gradual overheating and excessive vaporisation of the fuel limiting continuous safe use of the Score-Stove to two hours after which there is risk of fire hazard from fuel escaping due to excessive vapour pressure. In WBT laboratory experiments the fuel tank temperature was monitored to avoid risk of fire hazard and cooking with the Score-Stove. Restricting the air flow also increased the pollution created from combustion in the burner.
- In the interest of safety, excess air needs to be used to ensure that the kerosene is kept to a safe operating temperature. However, this reduces TAE efficiency, electrical output and the amount of heat transferred to the cooking pots.

## 6. Energy analysis and performance evaluation

Being a heat engine the Score-Stove TAE is limited by the second law of thermodynamics and Carnot's law so TAE efficiency is a function of the temperature difference between HHX and AHX. Fig 5 shows heat flows of the stove under test and Table 2 shows the component shares of energy distribution during a WBT test.

It was noted that the total energy requirements for boiling in the Score-Stove was higher (for about 39 mins) compared to boiling the same pot of water directly using the conventional pressurised kerosene burner (typically for about 10 mins). This is because in the conventional stove the flame directly comes in contact to the pot and the temperature difference across the water in the pot and the flames are higher which facilitated a greater rate of heat transfer and faster heating. In the case of Score-Stove, the flame from the burner first passes by the TAE and then reaches the boiling pots in sequence, which reduces flame temperature thus reducing the temperature gradient and the rate of heat transfer. In the unit tested, waste heat from the AHX is vented to atmosphere and so is not doing useful work.

Higher flame temperatures would have been achieved by restricting the air flow and keeping combustion closer to stoichiometric conditions (less excess air). However, laboratory experiments showed that this higher flame temperature caused gradual overheating of the fuel tank as more heat started to be conducted through the metallic fuel line up to the burner. This increased the vaporisation of kerosene fuel, which increased the fire risk significantly and so was considered unsafe for field trials. The problem also could be solved by reorienting the fuel tank and connecting it with a non-metallic high-temperature withstanding pressure hose. However this would compromise the simplicity of the present design and convenience of directly plugging in the very popular pressurised kerosene stove. So in practice with the common pressurised kerosene burner design there is limitation regarding increasing of flame temperature hence the heat transfer rate decreases causing longer time requirement of the Score-Stove for performing the WBT.

Table 2: Energy Distribution of Score-Stove, first WBT run up to 80°C in Pots after 39 min

| INPUT ENERGY COMPONENT | Value |
|---|---|
| Fuel consumption @ 26°C room | 0.194 kg |
| Assumed Burning efficiency | 95% |
| Input heating Rate | 3325W |
| Total Energy during WBT (100%) | 7780 kJ |

| ENERGY CONSUMPTION | kJ | Share |
|---|---|---|
| Pot-1(conv. 80°C + evap, 50 mg) | 565 | 11.4% |
| Pot-2 (conv. 64°C + evap, 0 mg) | 319 | 11.4% |
| Heat absorbed by Cooling Water | 1297 | 16.7% |
| Heat lost from Exhaust Gases | 986 | 12.7% |
| Heat loss from Cooking Pot | 140 | 1.8% |
| Heat loss from Hot Stove surface | 1193 | 15.3% |
| Heat loss from Chimney surface (open) | 387 | 5% |
| Radiation loss from Exposed Flame | 790 | 10.2% |
| Heat absorbed by ~ 90kg Metallic Mass | 1377 | 17.7% |
| Energy as sound (estimated) Considering 5% alternator efficiency | 180 | 2.3% |
| Unaccounted Energy losses | 555 | 7.2 % |

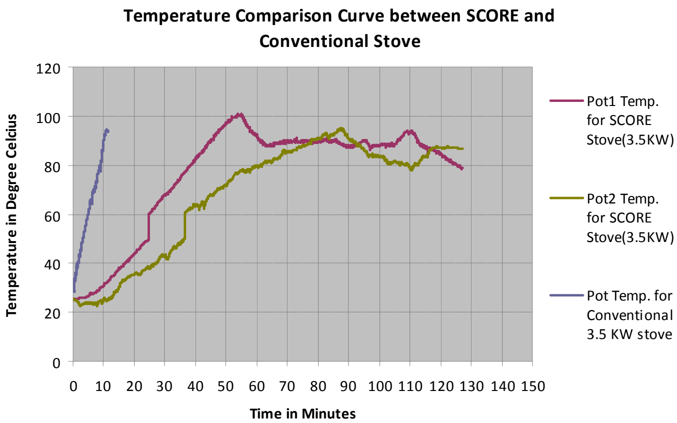


Fig. 6. Thermal lag of heating water in SCORE-Stove compared to conventional stoves.

Table-3: Typical Emission Characteristics from Score-Stove using two fuels

| | Kerosene Burner | Wood Burner |
|---|---|---|
| Excess Air % | 127 | 23 |
| Flame Temperature °C | 900 | 900 |
| Hot Heat Exch. Surface Temp °C | 580 | 550 |
| Exhaust Temp at Chimney Exit °C | 150 | 122 |
| CO ppm | 138 | 1997 |
| $CO_2$ % | 6.8 | 12.6 |
| $CO/CO_2$ ratio | 0.002 | 0.262 |
| Remaining Oxygen % | 11.7 | 3.9 |

Fig 6 shows the time lag of heating water in the Score-Stove compared to the conventional pressurised kerosene stove. Increasing the insulation to improve the heat transfer was tried, and delayed the heat losses. However, eventually the kerosene tank ended up in similar thermal conditions, with very little effect on fuel consumption.

In addition to the WBT cooking was performed; eggs were boiled and vegetables and rice cooked. The food tasted as usual and enough lighting was generated for cooking. Tests were also carried out with a specially designed wood burner replacing kerosene. The smoke was channelled out of the kitchen through a 50mm diameter chimney, ensuring a much healthier atmosphere inside the kitchen. Back pressure from chimney piping was small and natural convection easily exhausted the hot smoke. Updraft created in the chimney assisted the combustion process and enabled healthy cooking conditions compared to conventional stoves. Table 3 shows some comparison of emission measurements from test runs with pressurised kerosene and wood burners.

## 7. Areas for future research and development

The Score-Stove demonstrated a new way of producing electricity from waste heat, especially from heat lost during cooking. The following describe future work to overcome the limitations described in section 5 and 6:

- The requirements are that cooking time with electrical generation should be the same or better than the time of a conventional stove with the same fuel flow. Fig 6 shows that a 4-5 times improvement is required to achieve the target. This could be achieved by:
  - → Decreasing excess air from 127% to 30%, giving a target improvement of 2 times in heat transfer. (This will require a different kerosene/burner arrangement to ensure overall safety.)
  - → Utilising the waste heat from the TAE to part heat the water. Target improvement of 2 times.
  - → Improved insulation and heat transfer to the pot to bring the overall improvement to target.
  - → Alternatives are to redirect the hot gasses so that cooking or electrical generation can take priority.
- After a few test runs some condensation of water vapour was found to be occurring in the resonance tubes. Gradually some of this water vapour gets absorbed in the diaphragm of the linear actuator, dampens it and significantly reduces electrical power from the linear alternator on the next run. The problem was minimised by passing hot air through the resonance tube assembly for a while before each test run. This phenomenon was observed to some degree both in rainy and dry seasons, while the moisture content of ambient air varies significantly. Experience from other Score Centres has shown that this can be caused by sporadic leakage from the secondary AHX into the thermo-acoustic path. This happens under certain temperature profiles when the water pressure is higher than the acoustic gas pressure. Their solution will be applied in future.
- For most of the end-users the current space required by the Score-Stove is still too large. Closer integration of the TAE with the hobs could reduce the overall size as would coiling the resonant stubs. It is not recommended to use flexible corrugated tubes for the resonance air to allow reducing dimensional requirements as this will severely reduce TAE performance and may lead to no resonance at all.
- The TAE core has been designed to withstand 3 to 4 bar gauge pressure and plastic pipes are available up to 16 bar rating at 25$^{o}$C (They need de-rating for higher temperatures). After suitable pressure compliance testing at an acceptable safety factor, TAE pressure could be increased which will improve electrical output and system efficiency.

## 8. Conclusion

The Score-Stove provides a unique solution using thermoacoustic technology regarding the use of waste heat during cooking and the potential to produce small-scale electricity, especially for the people who do not have the access to mains electricity. The Score-Stove can use multiple fuels and also provides a healthier cooking environment for the people who use wood and biomass fuels.

The current design is acceptable for limited field trials to obtain end-user feedback. However, performance is lower than that required so expectations should be set accordingly.

Further adaptations are required to improve performance and ensure safety under typical end use. This is a rich area for further research and development and provided the changes give sufficient improvement, the Score-Stove has the potential to make an impact on the target users.

## References

[1] Bartlett, Sean . "New Study Estimates 4 Million Deaths from Household Cooking Smoke Each Year", press Release December 13, 2012 Global Alliance for Clean Cookstoves. http://www.cleancookstoves.org/media-and-events/press/new-study-estimates-4-million-from-household-cooking-smoke-each-year.html.

[2] Lim, Dr Stephen S et al. "A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990—2010: a systematic analysis for the Global Burden of Disease Study 2010", The Lancet, Volume 380, Issue 9859, Pages 2224 - 2260, 15 December 2012 , doi:10.1016/S0140-6736(12)61766-8

[3] http://anthro.palomar.edu/homo2/mod_homo_3.htm

[4] "Household Cookstoves Environment, Health, and Climate Change" http://climatechange.worldbank.org/sites/default/files/ documents/ Household%20Cookstoves-web.pdf
[5] SCORE website: http://www.score.uk.com/default.aspx.
[6] Riley, PH, "Affordability for sustainable energy development products", Journal of Applied Energy, Volume 132, 1 November 2014, Pages 308–316, DOI: 10.1016/j.apenergy.2014.06.050
[7] O'Shaughnessy, SM., Deasy, MJ., Kinsella, CE., Doyle, JV,. Robinson, AJ. "Small scale electricity generation from a portable biomass cookstove: Prototype design and preliminary results". Journal of Applied Energy Volume 102, issue C, 2013 pp 374-385. http://dx.doi.org/10.1016/j.apenergy.2012.07.032.
[8] http://www.biolitestove.com/news-press/news-events/news/biolite-special-field-report---the-homestoves-introduction-in-laos.html
[9] Riley, P.H., Saha, C., and Johnson, C.M., "Designing a Low-Cost, Electricity Generating Cooking Stove", Technology and Society Magazine IEEE, summer 2010. Digital Object Identifier 10.1109/MTS.2010.937029, 1932-4529/10/$26.00 ©2010 IEEE
[10] http://en.wikipedia.org/wiki/Electricity_sector_in_Bangladesh
[11] http://www.bpdb.gov.bd/bpdb/index.php?option=com_content&view=article&id=5&Itemid=6
[12]https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0CCUQFjAA&url=http%3A%2F%2Fww.powerdivision.gov.bd%2Fpdf%2FREP_English.pdf&ei=1FHfU8CYMs-v7AbPUA&usg=AFQjCNGGT7uDREQ7gqoSD_e1nQ6Dxq89yw&bvm=bv.72197243,d.ZGU
[13]Chen, B., Abdalla Abakr, Y., Riley PH., Hann, D. "Development of thermoacoustic engine operating by waste heat from cooking stove " AIP Conf. Proc. 1440, pp. 532-540; doi:http://dx.doi.org/10.1063/1.4704259 (9 pages)
[14] http://www.aster-thermoacoustics.com/wp-content/uploads/2013/09/Design-and-build-of-a-50W- thermacoustic-generator2.pdf
[15] Gardner DL., and Swift, GW. A cascade thermoacoustic engine, J. Acoust. Soc. Am. 114 (2003), pp. 1905–1919.
[16] Backhaus, S. & Swift, GW. (2000): A thermoacoustic-Stirling heat engine: Detailed study. Journal of the Acoustical Society of America, 107[6], pp. 3148-3166, 2000.
[17] Higgins B., Nicholson's Journal I, 130, 1802
[18] J Lord Rayleigh, "The explanation of certain acoustical phenomena", Nature, Lond.18, 319 (1878)
[19]R.L. Carter, M. White, and A.M. Steele, Private communication of atomics international division of North American aviation, Inc., September 24 (1962)
[20] Swift, GW. (1988). "Thermoacoustic engines". J. Acoust. Soc. Am. 84: 1145–1180. doi:10.1121/1.396617
[21] http://www.lanl.gov/thermoacoustics/DeltaEC.html
[22] http://www.aster-thermoacoustics.com/?page_id=403
[23] Sanchez, T., Dennis, R., Pullen, KR., "Cooking and lighting habits in rural Nepal and Uganda, Proceedings of the Institution of Mechanical Engineers." Part A: Journal of Power and Energy 0957650913498872, first published on September 12, 2013 as doi:10.1177/0957650913498872
[24] https://www.youtube.com/watch?v=FMpiOhfI790&list=UUa1eddRA3l7sfg4Zt2y0d9w.
[25] Chen, B., Riley, PH., et al., "Design and Testing of a Wood Burning Electricity Generator by using Dual-Core Thermoacoustic Engine". 2011 World Congress on Engineering and Technology (CET), Shanghai, China, 2011