Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 75 (2015) 137 – 143

Energy Procedia

The 7th International Conference on Applied Energy – ICAE2015

Design, Fabrication and Evaluation of Gamma-Type Stirling Engine to Produce Electricity from Biomass for the micro-CHP system

Hojjat Damirchi[a], Gholamhassan Najafi[a*], Siamak Alizadehnia[b] , Barat Ghobadian[a], Talal Yusaf[c] and Rizalman Mamat[d]

[a] *Department of Mechanics of Biosystem Engineering, TarbiatModares University, Tehran, Iran*
[b]*MSC. , Mech. Eng., IPCO, Tehran, Iran*
[c]*Faculty of Engineering and Surveying, USQ University, Toowoomba, Australia*
[d]*Faculty of Mechanical Engineering, University Malaysia Pahang, Malaysia*

Abstract

With consideration of the biomass energy potential, a gamma type Stirling engine with 220cc swept volume and 580cc total volume was designed, optimized and manufactured. The engine was tested with helium. Working characteristics of the engine were obtained within the range of heat source temperature 370- 410˚C and charge pressure 10 bar for biomass resources and heat source temperature 540- 560 ˚C and range of charge pressure 1-12 bar with 1 bar increments at each stage for gases. By using of thermodynamic and heat transfer design methods, the key parameters of the designed Stirling engine like required surfaces for heat transfer were calculated (hot side 307 and the cold side 243 squares of centimeters). For analysis of fluid flow, two-dimensional flow analysis method was performed by the software CFD methods. The principles of thermodynamics as well as Schmidt theory were adapted to use for modeling the engine and then pressure - volume diagrams of the thermodynamic and Schmidt analysis were compared. During the test, the temperature is monitored by thermocouples and the pressure of the working fluid helium is monitored by pressure sensors. Indicated power, friction power and brake power were measured and maximum brake power output was obtained with helium at 550˚C heat source temperature and 10 bar charge pressure at 700 rpm as 96.7 W. Electrical energy produced from biomass sources. Sugarcane bagasse, wood, wheat straw, poplar wood and sawdust as fuel system were selected. Most power be obtained from the sawdust (46 watt) and pruning of trees for wood for low power (21 watts), respectively. Minimum ignition time of the Sawdust (4 min) and the most time flammable wood from pruned trees (10 min) was measured. At maximum power, the internal thermal efficiency of the engine was measured as 16%. The test results confirm the fact that Stirling engines driven by temperature of biomass gases are able to achieve a valuable output power. Results of the present work encouraged initiating design of a single cylinder, gamma type Stirling engine of 1 kWe capacity for rural electrification.

Peer-review under responsibility of Applied Energy Innovation Institute

Keywords: Stirling engine; Biomass; Schmidt analysis; Flow analysis; Electricity production; MCHP.

Peer-review under responsibility of Applied Energy Innovation Institute
doi:10.1016/j.egypro.2015.07.240

1. Introduction

Stirling engines have been investigated as the new technology for micro combined heat and power applications. As external combustion engines permitting close control of the combustion process, their characteristics of low emissions, high efficiency, reliability, extended service intervals, low noise and vibration levels are all well suited to the demands of micro-CHP with stirling engines systems [1]. The performance of Stirling engines as external combustion engines meets the demands of the efficient use of energy and environmental security and therefore they are the topic of present attention in technical investigate and engineering requests [1]. Among external combustion engines, Stirling engines has been investigated due to numerous benefits such as the ability to operate from any heat source, quiet operation with low noise and vibration releasing low pollutant emissions, requiring less maintenance and high efficiency [2]. Stirling engine can operate with heat as energy input and can produce electricity. These engines could be applied to the MCHP systems (Micro Combined Heat and Power) driven by solar, biogas, mid-high temperature waste gases [3].

2. Materials and Methods

It has been proved that a practical Stirling cycle always departs significantly from the ideal cycle mainly due to the performance of the heat exchanger and the regenerator. Some detailed analysis with practical values and examples of the engine are given by Organ [4]. For this calculation model the equation set of Urieli and Berchowitz is used. Fig. 1 shows the model that the analysis is based on. A Stirling engine consists of mainly five spaces: compression (c), cooler (k), regenerator (r), heater (h) and expansion space (e), so there are five interfaces, displayed in Fig. 1.

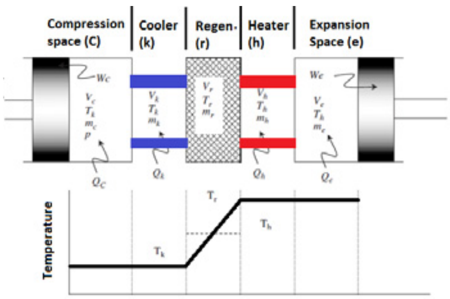
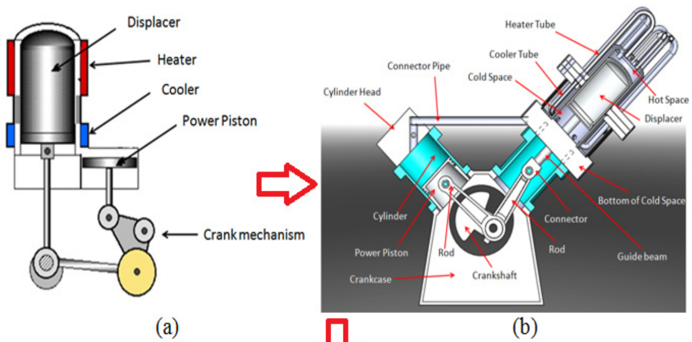


Fig. 1. Calculation model

The engine analysis is done for the heat transfer to working gas by evaluating the area enclosed in PV diagram. For the analysis it has been assumed that total mass of working gas in the machine is constant.

The first analysis of a Stirling engine was published by Schmidt in 1871 [5]. Schmidt obtained close theory, which provides sinusoidal volume variation of working space in the reciprocating engines. Theory retains the major assumptions of isothermal compression and expansion and of perfect regeneration. It, thus remains highly idealized, but is certainly more realistic than the ideal Stirling cycle. Stirling engines employ air, hydrogen, helium and nitrogen as working fluid. Commonly, due to higher heat transfer capabilities of hydrogen and helium, these gases are applied. Hydrogen is thermodynamically a better choice, however not safe to work. Helium is a noble gas and safer to use. With consideration of the biomass energy potential, a gamma type Stirling engine with 220cc swept volume and 580cc total volume was designed, optimized and manufactured (figure 2). The engine was tested with helium.



Dimension	250 x 380x520 mm
Weight	20kg
Piston Diameter	70mm
Displacer Diameter	69mm
Stroke	50mm
Working gas	He
Power	100W
rpm	600rpm
Hester Temp	550°C
Cooler Temp	30-50°C

(c)

Fig. 2. (a) and (b) Schematic diagram of Stirling engine , (c) Real Stirling engine and its specifications

The manufactured stirling engine has been evaluated by different procedures to measure the performance parameters with coupling of pressure sensor, cranck angle encoder, thermocouple (figure 3). Then for produce electricity from biomass, system coupled with CHP system (figure 3).

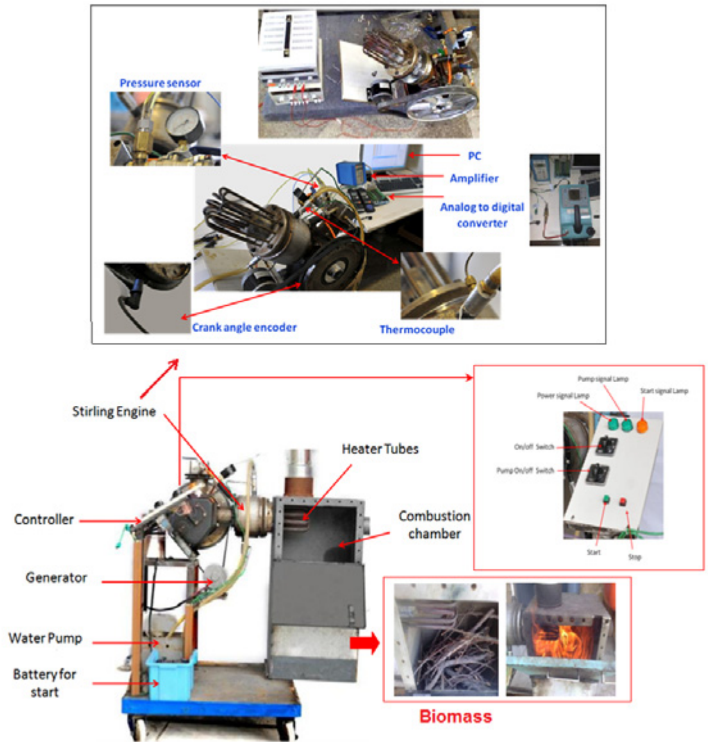


Fig. 3. Coupling of stirling engine with micro combined heat and power (MCHP) system

3. Results and discussions

By using of thermodynamic and heat transfer design methods, the key parameters of the designed Stirling engine like required surfaces for heat transfer were calculated (hot side 307 and the cold side 243 squares of centimeters). For analysis of fluid flow, two-dimensional flow analysis method was performed by the software CFD methods. results of CFD analysis has been indicated at figure 4.

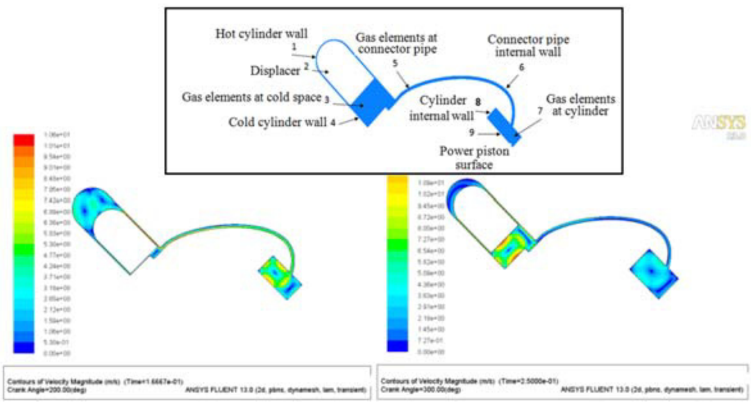


Fig. 4. CFD analysis of stirling engine

The principles of thermodynamics as well as Schmidt theory were adapted to use for modeling the engine and then pressure - volume (P-V) diagrams of the thermodynamic and Schmidt analysis were compared and results proved that there is good agreement between thermodynamics and Schmidt analysis (figure 5). Indicated power, friction power and brake power were measured and maximum brake power output was obtained with helium at 550˚C heat source temperature and 10 bar charge pressure at 700 rpm as 96.7 W (figure 6).

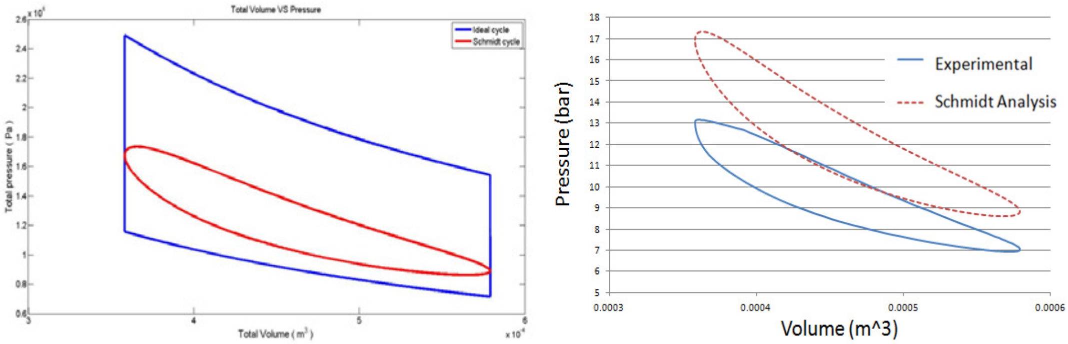


Fig. 5. (a) P-V diagram for ideal cycle with Schmidth cycle, (b) Comparison of P-V diagram for ideal cycle with Schmidth cycle

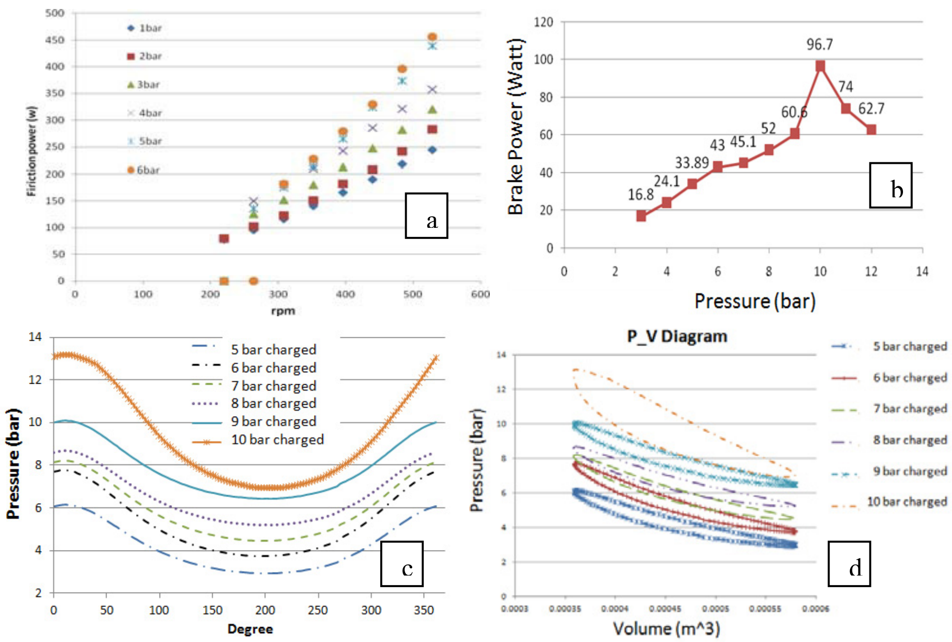
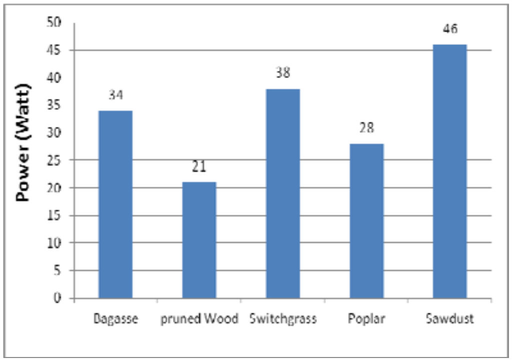


Fig. 6. (a) Friction power, (b) Brake power and (c) Indicated power (pressure) of tested stirling engine, (d) P-V diagram

Electrical energy produced from burning of biomass and flammable agricultural wastes (biomass sources). Sugarcane bagasse, wood resulting from pruning orchards, wheat straw, poplar wood and sawdust as fuel system were selected. Most power be obtained from the sawdust (46 watt) and pruning of trees for wood for low power (21 watts), respectively. Minimum ignition time of the Sawdust (4 min) and the most time flammable wood from pruned trees (10 min) was measured. At maximum power, the internal thermal efficiency of the engine was measured as 16%. The test results confirm the fact that Stirling engines driven by temperature of biomass gases are able to achieve a valuable output power. (figure 7).



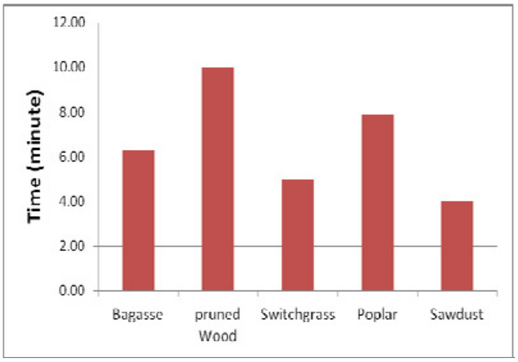


Fig. 7. Electrical power produced from burning of biomass and flammable agricultural wastes (biomass sources) (b) Ignition time of biomass sources

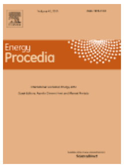
5. Conclusions

The test results confirmed the fact that Stirling engines driven by temperature of biomass gases are able to achieve a valuable output power. Maximum brake power output was obtained with helium at 550˚C heat source temperature and 10 bar charge pressure at 700 rpm as 96.7 W. Electrical energy produced from biomass sources. Most power be obtained from the sawdust (46 watt) and pruning of trees for wood for low power (21 watts), respectively. Minimum ignition time of the Sawdust (4 min) and the most time flammable wood from pruned trees (10 min) was measured. At maximum power, the internal thermal efficiency of the stirling engine was measured as 16%. Results of the present work encouraged initiating design of a single cylinder, gamma type Stirling engine of 1 kWe capacity for rural electrification.

References

1. Harrison, J. and E. On, *Stirling engine systems for small and micro combined heat and power (CHP) applications.* Small and Micro Combined Heat and Power (CHP) Systems, 2011, p.179-205.
2. Thombare, D.G. and S.K.Vermab, *Technological development in the Stirling cycle engines.* Renewable and Sustainable Energy Reviews, 2008. **12**: p.1–38.
3. García D., González , Prieto M.A. J.I., Herrero , S. López , S. Mesonero, I. and C.Villasante, *Characterization of the power and efficiency of Stirling engine subsystems.*Applied Energy, 2014. **121**: p.51–63.
4. Organ A. J., Jones J. N. and K. Gether, *Characterization of Stirling engine pumping losses.* In:Proc. 1st International Stirling Forum, Osnabrück.1998, p.59e66.

5. Schmidt G. *Classical analysis of operation of Stirling engine. A report published in German Engineering.*Union (Original German), vol. XV; 1871. 1987, p. 1–12.



Biography

Dr. Gholamhassan Najafi is assistant professor in Mechanics of biosystem engineering department, Tarbiat Modares University, Tehran, Iran. He got his Ph.D. in 2008 in the field of biofuels and internal combustion engines. He is expert in the fields of internal combustion engines and renewable energies.