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A Study on Critical Assessment of TEG (Thermo Electric Generator) Efficiencies & a Possible Application

S Ganeshpavan, Y Srinath, CSB Dixit, HS Mukunda

Centre for Disaster Mitigation

Jain University, Jakkasandra 562 112

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Thermo Electric Power Generation

- TEG converts thermal energy to electrical energy
- Temperature difference between two dissimilar electrical conductors or semiconductors produces a voltage difference
- TEGs can be used for power production possible in remote areas

$$\textbf{TEG Efficiency} = \frac{\textbf{Output electric power}}{\textbf{Thermal power Input}}$$

Thermoelectric materials

Material	Hot Face T°C	η %	$ /unit
Bi_2Te_3	320	4-5	30-60
Snsb	240	5	25
Hybrid BiTe - PbTe	360	7	98
Calcium Manganese oxide(CMO)	800	7-8	300
CMO cascade with BiTe	600	6	350

Bismuth Telluride is widely available device in market

This study examines the performance of Bi-Te based devices

Make	thk mm	Size mm	Flux W/cm^2	O/P W	AC res Ω	I/P W	η %	$
TEG power, & Customer Electric Canada	4.3	30x30	13.2	5.2	2.7-3.6	115	4.5	20
	5.1	40x40	9.2	5.1	0.8-1.0	113	4.5	36
	6.0	56x56	11.6	7.5	0.5-0.7	152	4.9	52
	8.0	56x56	10.4	13.0	0.7-1.0	325	**4.0**	62
Hi-Z Tech USA	5.1	29x29	9.54	2.5		80	4.5	30
	6.5	62x62	5.52	9		217	4.5	45
	5.1	62.62	9.54	14		375	4.5	70
	5.1	75x75	9.54	19		536	4.5	109
TEGPro, US	5.0	56x56	12.3	19.3		356	**5.4**	59
Marlow China	3.4	30x34		4.0			5.0	30
	4.0	40x48		6.2			5.0	45
Wellen Tech China	3.6	30x30		1.2				
	4.8	40x40		1.6				
	4.5	50x50		2.4				

- Rated module η ranges from 4 to 5.4 %
- Thicker modules are expensive, with lower I/P flux

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Earlier work in this area

Lab.	Module (Rated η)	No.	O/P W	Flux W/cm^2	η %
Risha Mal et al., TEG Integrated Cookstove: a Sustainable Approach of Waste Heat to Energy Conversion *Centre for Rural Development and Technology,* ***IIT Delhi***	HZ-9 BiTe, **(4.5%)**	1	4.0	5.5	1.8
C. Lertsatitthanakorn et al , Study of Combined Rice Husk Gasifier TEG, **Thermal Processes Research Lab, Thailand**		2	3.9	-	2.0
D. Champier et al., TEG power from biomass cook stoves, **Paul Valery University, France**	TEP1 BiTe, (**4.5%)**	4	7.0	5.2	1.1
Dan Mastbergen et al, Producing Light from Stoves using a TEG **Engines &Energy Conv. Lab CSU, USA**	TEP1-1.5 BiTe, (**4.5%)**	1	3.8	8.3	2.8

- Max. O/P is about half the rated O/P and so is η
- Heat flux is also lower. (Lower flux modules are expensive)

Commercially Available TEG products

Product Name		Modules	O/P W	I/P W	η %	Cost $
TEG12- 24VDC Forced Air cooling		8	20	920	2.1	429
TEG12 -24VDC liquid cooled		12	50	1776	2.8	629
TEG stove top		4	10	460	2.2	205

- Based on thermal i/p and rated o/p, claimed η are about half the rated even in these commercially available devices

TEG Efficiencies: The Question

- Rated module η is nearly twice of module η based on claimed device o/p both in research mode & commercially available Thermo Electric power Generators

- Assessment of efficiencies of TEG modules are carried out to understand this large difference

- **A 4 TEG device built and tested will be described**

- Module used: TECTEG power module
  Size: 30x30mm, t: 4.3 mm
  Rated Flux: 13W/cm^2 ΔT: 270 ^{0}C
  Max. Power: 5.2W, Rated I/P: 115 W
  10 nos procured

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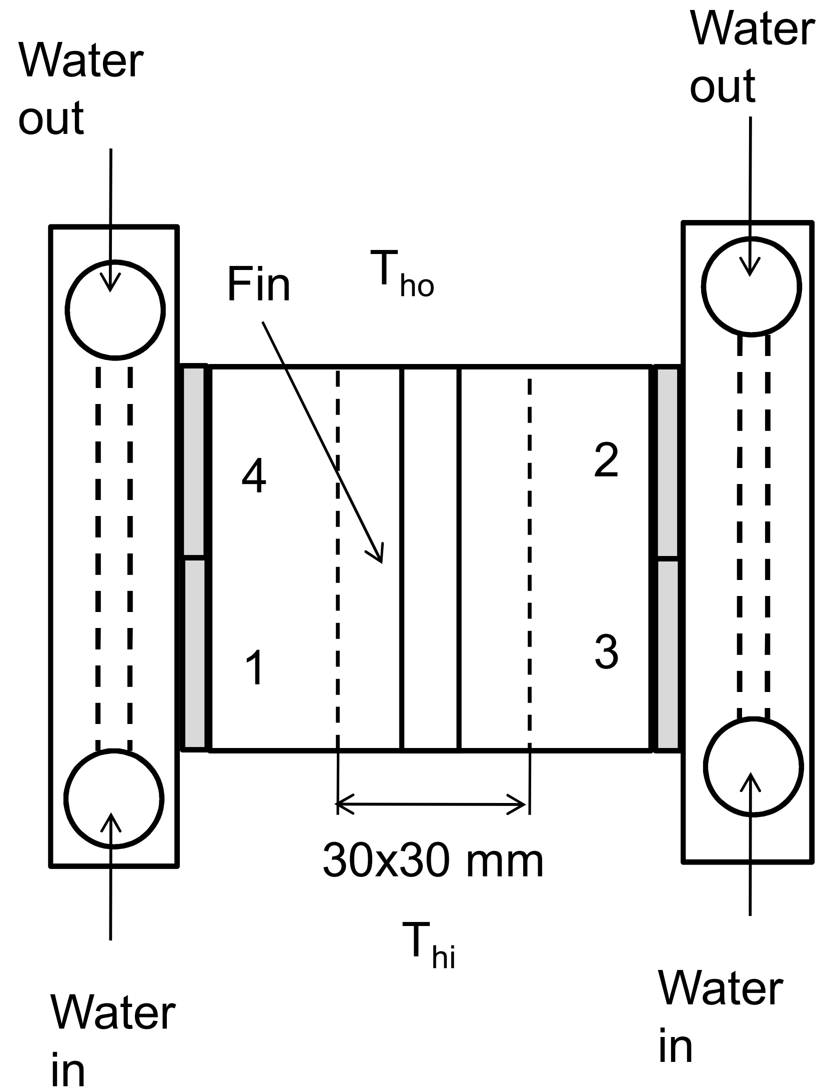
Configuration of device

- 4 module configuration with a heated core and cooled boundaries built
- Required heat input: 460 W
  Required Flux: 13 W/cm^2
- Cooling water flow requirement:
  ~2.0 *l* /min, ΔT of about 3 ^oC
- Max Hot face temperature:
  300^o C ΔT across TEG: 270 ^oC
- Two HE with 230 W capacity each (flow rate 1 *l*/min each) used



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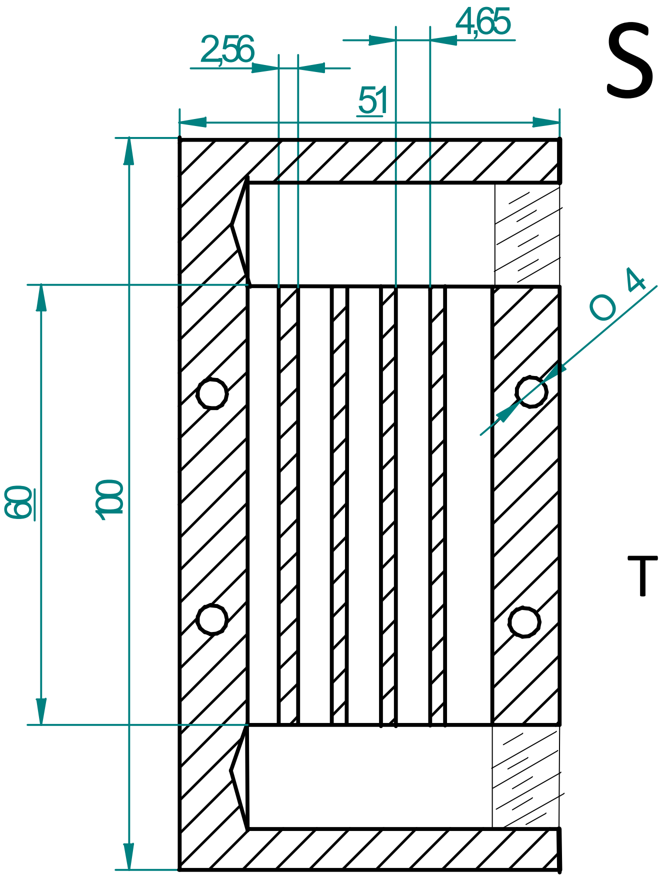
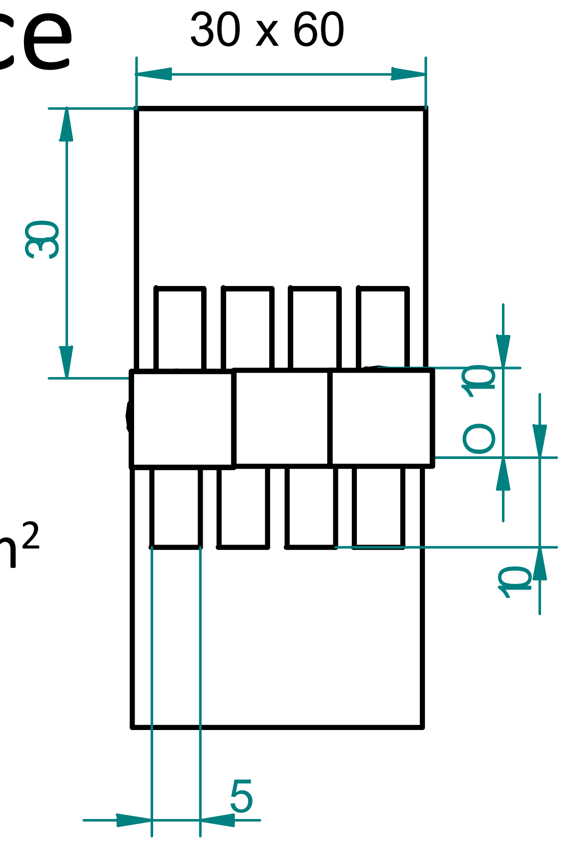
Sink Source





TEG Mount Area: 18 cm^2
(For 2 TEGs)

Al body, Water Flow: 1 *l*/min
TEG heat flux = 13 W/cm^2
Water Vel. = 0.2 m/s
HE area = 44 cm^2
Heat Flux to water = 5.4 W/cm^2

Al Body, Hot Face T: 300 ^oC
Fin base T: 311^o C,
Gas Avg. T: 750 ^{o} C
HT Coeff: 9 W/m^2K
Fin surface Heat Flux: 3.8 W/cm^2

Experimental Setup

DAQ:

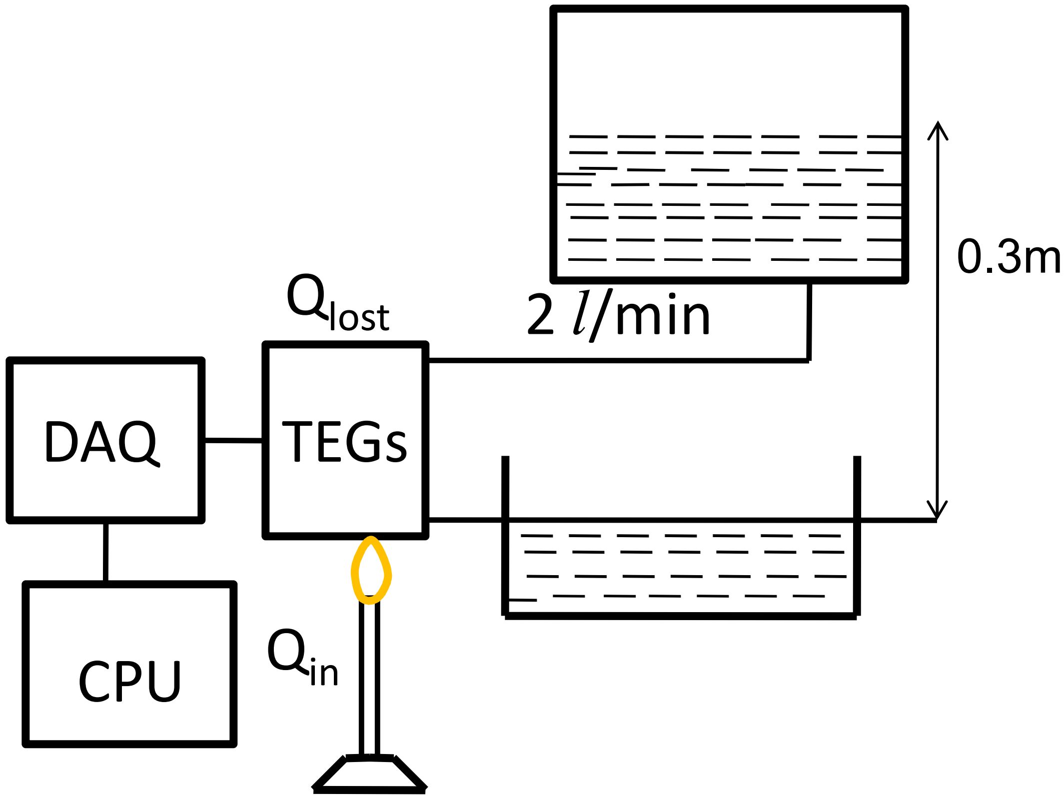
IOTECH Daq 56, 80Hz, 10 Ch.,
K-- TC & V EQUINOX 4 Ch, ,
Type-K TC

Heat Source:

Nom. LPG Flow: 60 g/h
(Nozzle: 20 No, 0.83 mm Dia
Gas Pr.: 325 mm H_2O

Cooling Water:

50 l tank, Nom. flow: 2 l/min
Nom. Head: 0.3 m



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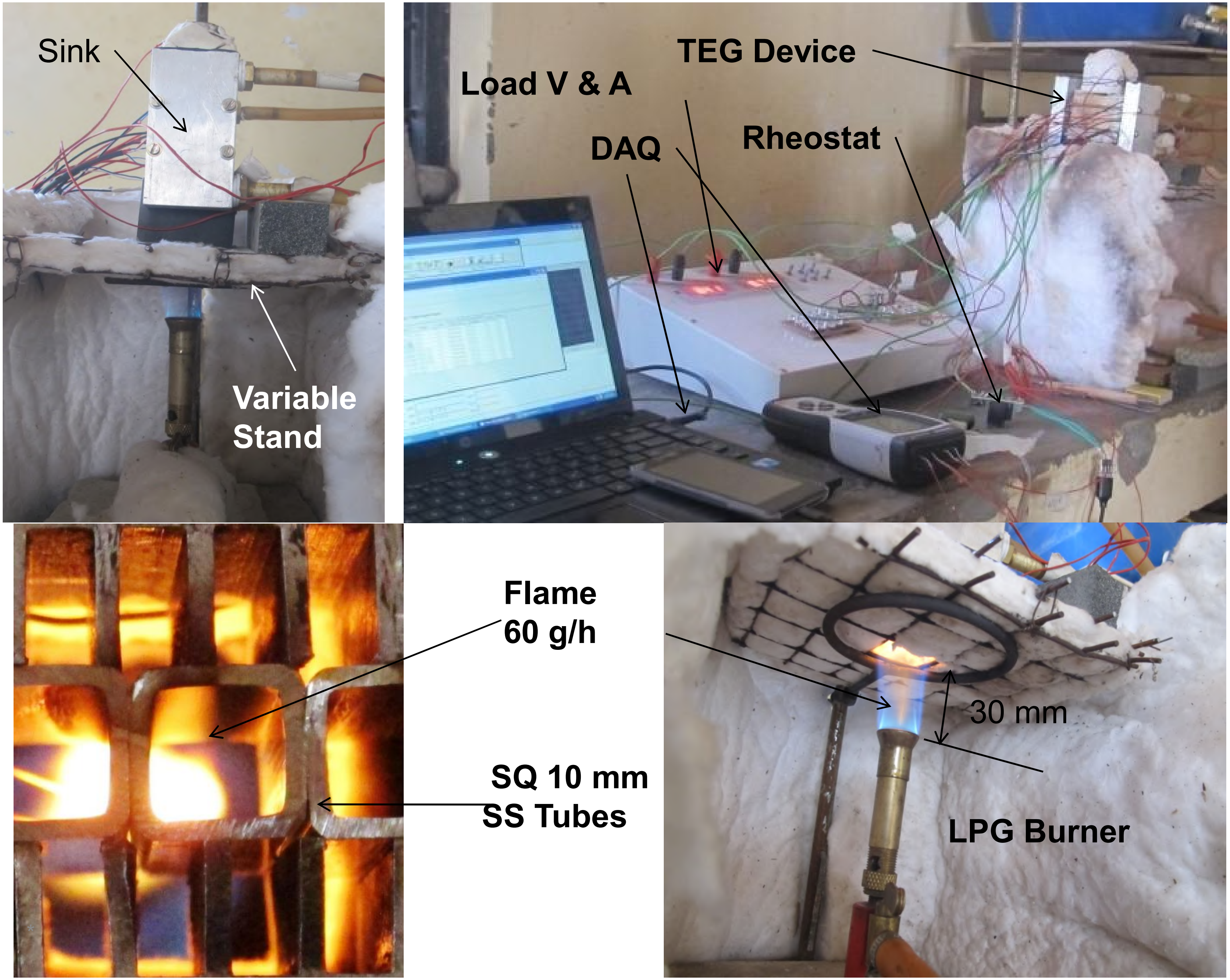
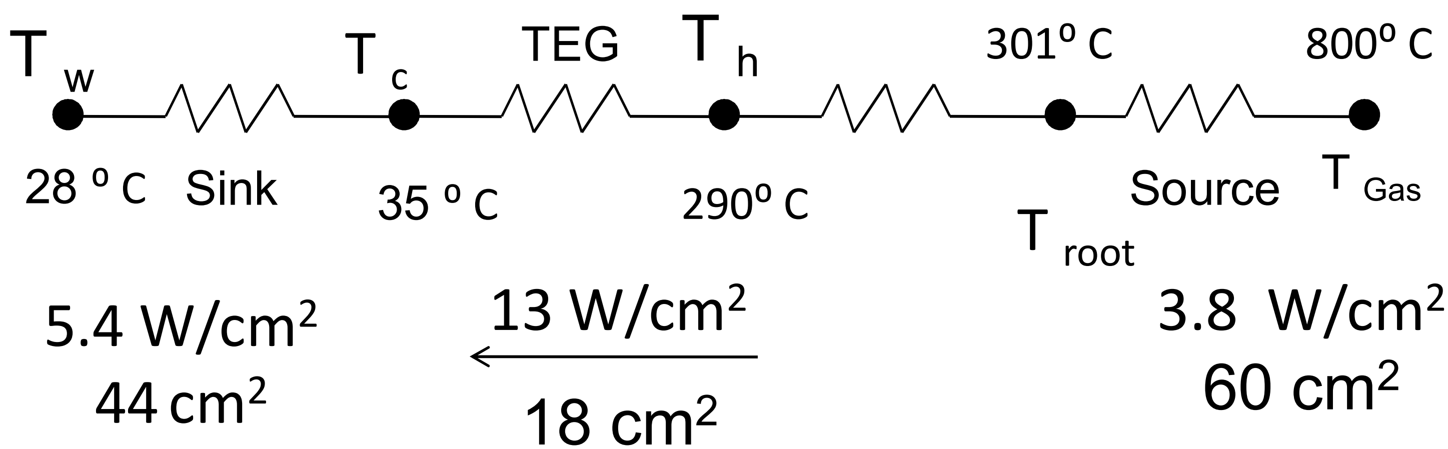

Sink
Variable
Stand
TEG Device
Load V & A
DAQ
Rheostat
Flame
60 g/h
SQ 10 mm
SS Tubes
30 mm
LPG Burner

Test Parameters

Heat source	Bunsen burner
Fuel	LPG
Fuel rate	Peak Flow 60 g / h
Thermal contact	Graphite Sheet, Tightening Torque: 0.7 N-m
Data acquired	T Hot gas in and out, T hot and cold face of 4 TEGs, T water in and out, Voc O/P of 4 TEGs, Current of resistor Loaded TEG



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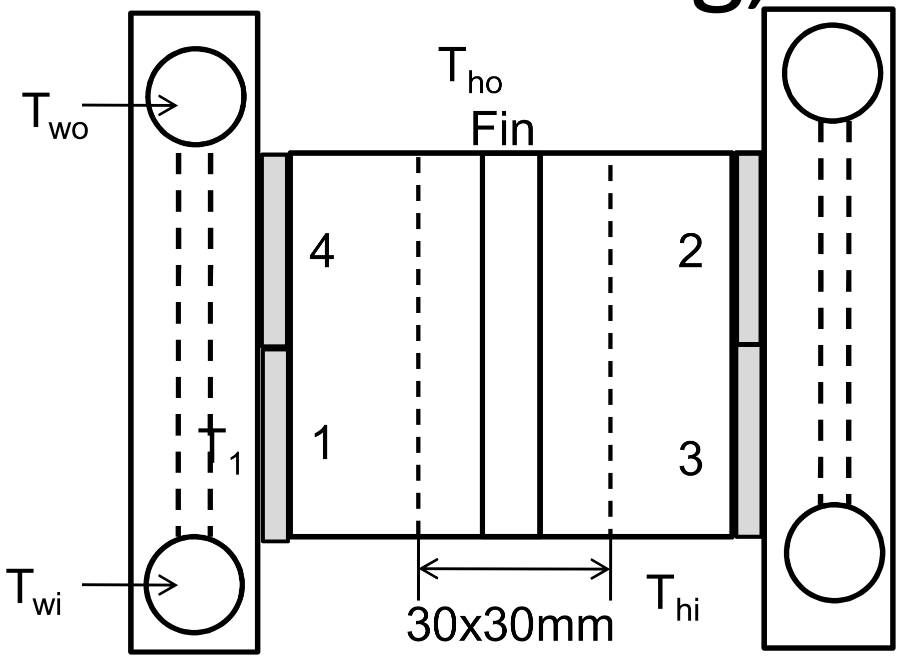
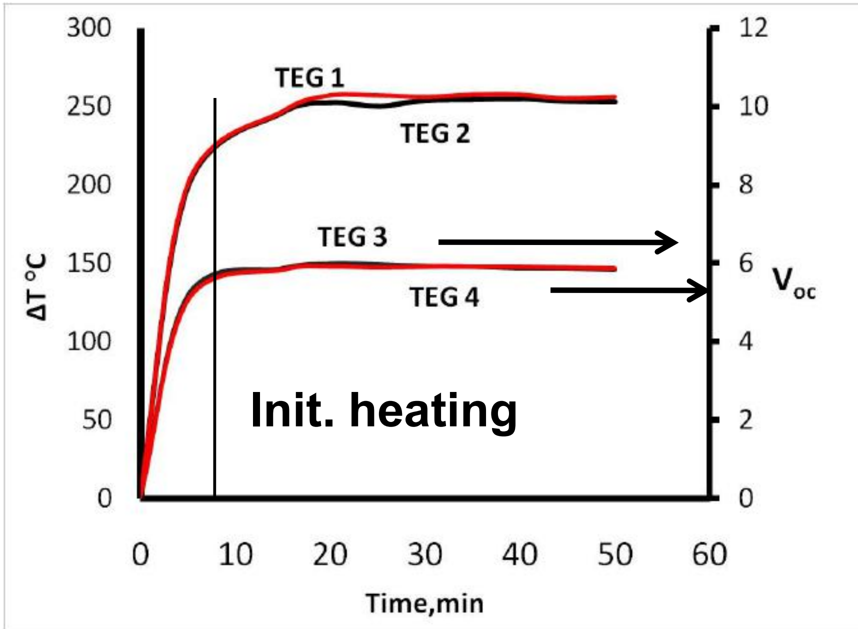
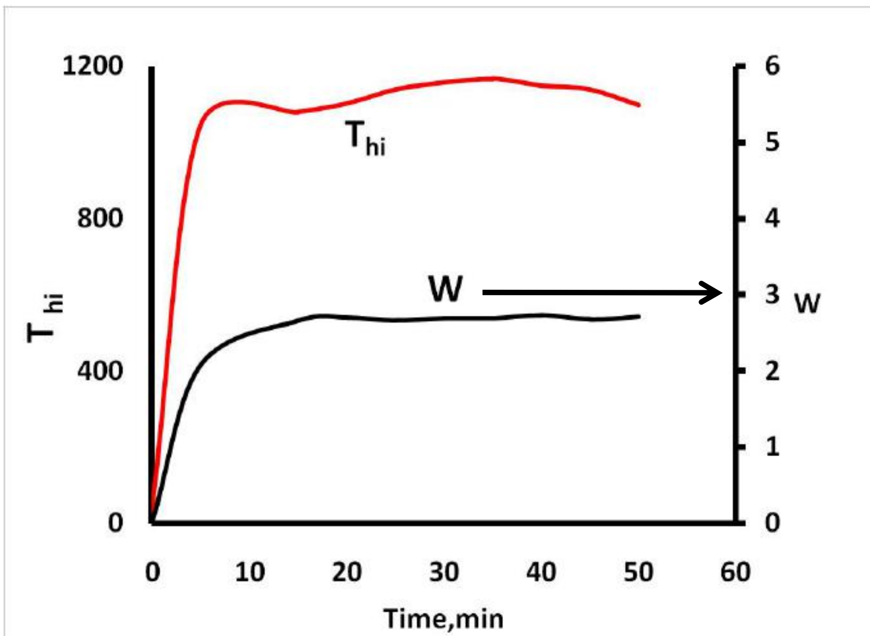
Testing, Resistive Load







- Resistive load testing: const. power o/p of ~2.5 W/mod. within 10 min at 1000 C inlet T
- Low water flow (2 l/min), handled in gravity flow mode
- Over 50 h of testing completed

Hot gas inlet T Effects

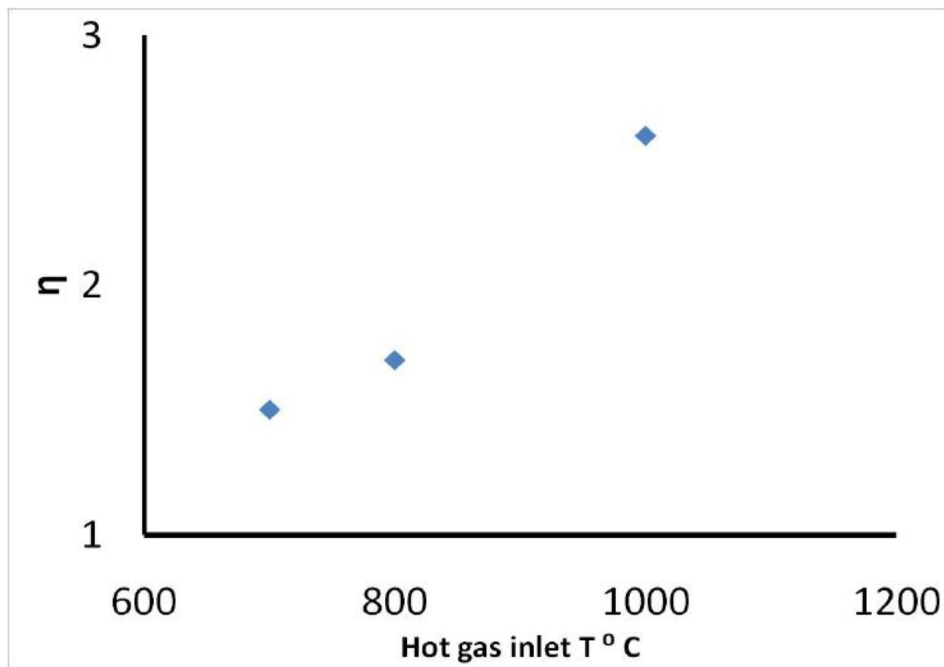
- Highest flux was achieved at hot gas T of about 1000 C by LPG

- To test for suitability for biomass fuel, inlet T was reduced

- Testing at reduced inlet T has indicated fall in efficiency

- Usable o/p obtained at inlet Hot gas T of about 700 C

Inlet ^{o}C	TEG Flux, W/cm^2	I/P W	O/P W	η %
1000	11.3	101	2.7	2.6
800	9.7	87	1.5	1.7
700	8.5	77	1.2	1.5



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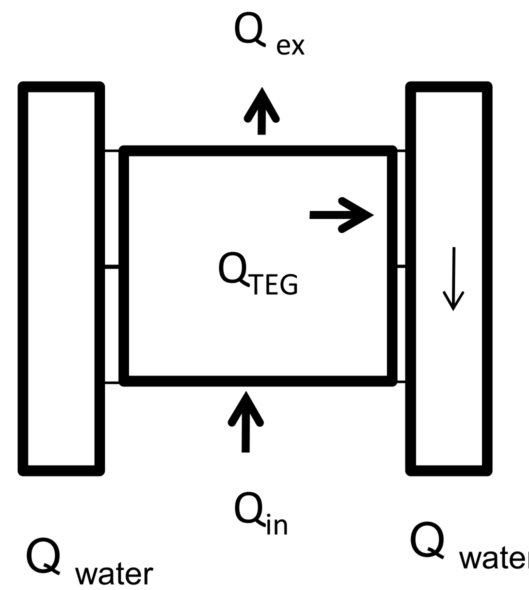
Power balance

g/h	60	30	20
Input, W	**804**	**402**	**268**
Exit hot gas, W	313	151	101
cooling water, W	**403**	**210**	**140**
Unaccounted, W	88	41	27

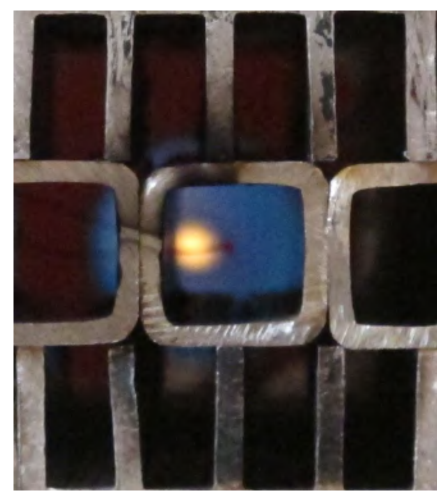


More than half the i/p flows thro TEG

60 g/h

30 g/h

20 g/h



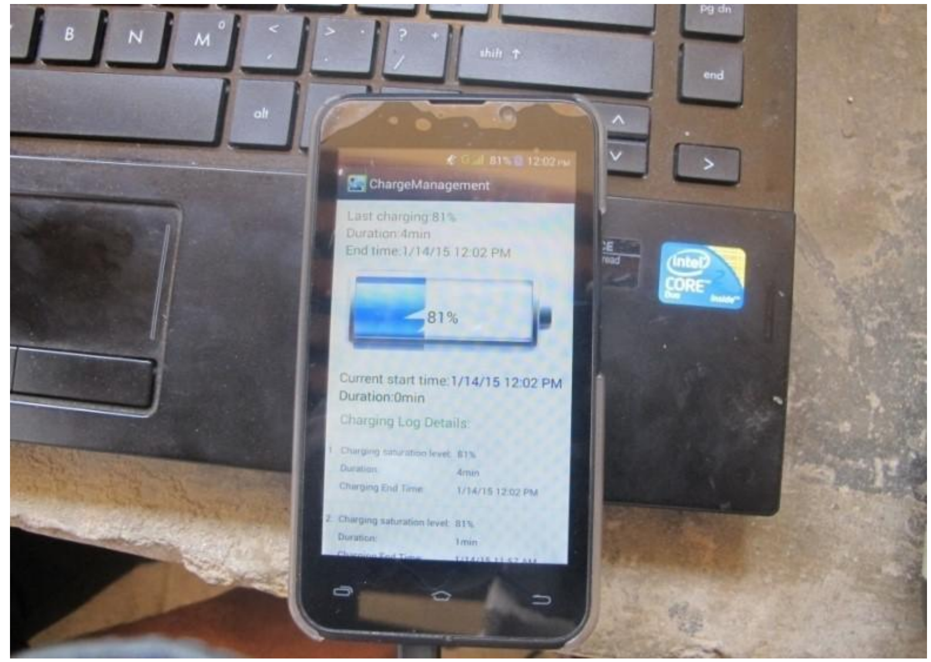
Testing for Battery Charging

- TEG power best used in storage mode

- Device tested for battery charging

- 1.6 AH Smart phone battery charged with TEG 1 O/P using DC-DC convertor

- 6V open circuit voltage regulated to 4.2 V with charging current 0.6 A



Conclusions

- Study of TEG literature has indicated large gap in rated module efficiency & achievable efficiency in device form
- Our testing following prescribed mounting techniques also confirms this fact
- Gravity based water cooling is sufficient even for highest flux TEG used
- Use of fins at hot gas end is required to meet high flux demand
- Al material fins (2.5 mm Thick) appears to be adequate & can tolerate peak hot side T of ~320 C
- Hot side configuration needs design modification to accommodate biomass heat source
- The configuration appears to be ideal for combined heat and power generation from biomass

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Thank You

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