STOVE MODEL II

This model has a concentrator disc of dia. 11.5 cm (0.7 dia. of the combustor) and riser of diameter 15.5 cm/ height 8.5 cm from the concentrator disc. Also for supporting a pot support or even the vessel itself a cover was made with outer chamber of the previous stove model.

Part	Diameter/ Breadth (cm)	Height (cm)	Volume
Outer Shell	23.5 x 23.5 square	32	15 litres
Combustion chamber	16.5 dia.	22	5 litres
Concentrator disc	11.5 dia. (hole)	NA	NA
Riser	15.5 dia.	8.5	NA
Cover	23 x 23 square	8.5	NA

Air Inlet	Dimensions	Area
Primary air inlet area	1 cm dia. hole x 25	19.64 sq.cm
Secondary air inlet area	0.8 cm dia hole x (38+37)	37.699 sq.cm

Secondary holes are kept about 4 cm below the concentrator disc in order reduce leakage problem found in the first one.

Fig. **Parts of the stove**

Testing on stove model II

Water Boiling Test

Method used: High Power Test –*COLD START*

Indoor testing of stove was done at Integrated Rural Technology Centre, Palakkad to find the efficiency to be 21.73% and 21.06% with riser and concentrator disc arrangement.

Outdoor Testing:

Procedure:

The evaluation was done by conducting a water boiling test on the chulah. The test conducted in the following manner.

- Known mass of firewood DRY COCONUT SHELL (M_f) was taken in to lumps.
- Known mass of water (M_{w1}) was taken in a vessel (The vessel selected so that it will rest on the stand over the stove)
- Initial temperature of water was taken (T_1)
- The stove was loaded with first lot of coconut shell and the fuel was burned.
- Fuel was loaded as and when the first lot were consumed for to maintain uniform rate of burning.
- Temperature of boiling water was taken (T_2)
- When the burning of firewood came to an end the vessel was allowed to cool on the stove itself and then removed to measure the mass of water remaining (M_{w2}).
- Mass of water evaporated = $M_{ev} = M_{w1} - M_{w2}$

The efficiency of stove was calculated as follows:

Input energy = Mass of fuel loaded x Calorific value of fuel.

Useful output = (Energy used to heat water from initial temperature up to stage of boiling + energy used for quantity of water evaporated)

= (Mass of water taken x Sensible heat x differences in temperature) + (Mass of water evaporated x Latent heat of water)

Percentage of efficiency = (Useful energy output/Energy input) x 100

$$= [M_{w1} \mathbf{x} S_w (T_2-T_1) + M_{wev} \mathbf{x} L] / [M_f \mathbf{x} C_{vf}] \times 100$$

S_w - Sensible heat of water (Specific heat) = 1 kcal/kg

L - Latest heat of vaporization of water = 540 kcal/kg

Cv_f - Calorific value of coconut shell used = 5000 kcal/kg

TEST-1 (on 26/12/2014)

Observations:

1. Firewood details:

A mixture of size 1.5 cm to 2 cm

Weight = 0.5 kg

2. Vessel details:

Type : Aluminium

Diameter : 22 cm

Height : 11 cm

3. Temperatures:

Ambient temperature : 29 ^{0}C

Temperature of water before heating : 28.8 ^{0}C

Temperature of boiling water : 99.7 ^{0}C

4. Other details:

Test started at 04:09 pm using 20 ml of kerosene. Gasification started by 4:11 pm and ended by 4:20 pm. Experiment was stopped by 4:22 pm and vessel was removed. Remaining water measured at 5:20 pm. Temperature of water then 36^{0}C.

5. Flame details:

Yellow

6. Smoke details:

Initial stage - Light Black

After 4 minutes - No visible smoke

After 8 minutes - No visible smoke

Efficiency calculations:

Mass of firewood loaded, M_f = 0.5 kg

Calorific value of fuel, C_f = 5000 kcal/kg

Initial temperature of water, T_1 = 28.8 ^{0}C

Mass of water taken, M_{W1} = 1.479 kg

Sensible heat of water (Specific heat), S_W =1 kcal/kg

Temperature of boiling water, T_2 = 99.7 ^{0}C

Mass of water remaining, M_{W2} = 1.1339 kg

Mass of water evaporated, M_{W1}-M_{W2} = 1.479 – 1.1339 = 0.3451 kg

Latent heat of evaporation of water, L = 540 kcal/kg

% of efficiency = (Useful energy output / Energy input) x 100

= {1.479x1(99.7-28.8) + (0.3451 x 540)} / (0.415 x 5000) x 100

= **14.03 %**

Table 6. Water temperature variation with time	
Time in minutes	Temperature (^{o}C)
0	28.8
5	88
10	99.7
20	67
30	54
40	46

Inference: Low efficiency is due to breeze affecting the flame formation as well as removal of the vessel from the stove soon after gasification stopped. Amount of char formed is 85 gms.

TEST-2 (on 26/12/2014)

1. Firewood details:

A mixture of size 1.5 cm to 2cm"

Weight - 0.5 kg

2. Vessel details:

Type: Aluminium

Diameter: 22 cm

Total height: 11 cm

3. Temperatures:

Ambient temperature : 29 ^{0}C

Temperature of water before heating : 28.5 ^{0}C

Temperature of boiling water : 99.8 ^{0}C

4. Other details:

Test started at 5:42 pm. Gasification started at 5:44 pm and ended by 5:54 pm. Remaining water measured at 7:20 pm and temperature of water then was 32^{0}C

5. Flame details:

Yellow

6. Smoke:

Initial stage - Light Black

After 4 minutes - No visible smoke

After 8 minutes - No visible smoke

Efficiency calculations:

Mass of firewood loaded, $M_f = 0.5$ kg

Calorific value of fuel, $C_f = 5000$ kcal/kg

Initial temperature of water, $T_1 = 28.5\ ^0C$

Mass of water taken, $M_{W1} = 1.479$ kg

Sensible heat of water (Specific heat), $S_W = 1$ kcal/kg

Temperature of boiling water, $T_2 = 99.8\ ^0C$

Mass of water remaining, $M_{W2} = 0.86275$ kg

Mass of water evaporated, $M_{W1}-M_{W2} = 1.479 - 0.86275 = 0.61625$ kg

Latent heat of evaporation of water, L = 540 kcal/kg

% of efficiency = (Useful energy output / Energy input) x 100

= {1.479x1(99.8-28.5) + (0.616 x 540)} / (0.5x5000) x 100

= **17.52 %**

Table 8. Water temperature variation with time	
Time in minutes	Temperature (^oC)
0	28.5
1	37
5	99
8	99.8
13	98
16	94

Inference: Efficiency improved as a result of allowing the vessel to cool on the stove itself. Efficiency may be slightly reduced due to the effect of wind.

TEST-3 (Stove with concentrator disc, on 27/12/2014)

1. Firewood details:

A mixture of size 1.5 cm to 2cm"

Weight - 0.5 kg

2. Vessel details:

Type: Aluminium

Diameter: 22 cm

Total height: 11 cm

3. Temperatures:

Ambient temperature : 32 ^{0}C

Temperature of water before heating : 31.5 ^{0}C

Temperature of boiling water : 99.8 ^{0}C

4. Other details:

Test started at 1:07 pm. Gasification started at 1:09 pm and ended by 1:18 pm. Remaining water measured at 2:40 pm and temperature of water then was 38^{0}C

5. Flame details:

Yellow

6. Smoke:

Initial stage - Light Black

After 4 minutes - No visible smoke

After 8 minutes - No visible smoke

Efficiency calculations:

Mass of firewood loaded, M_f = 0.5 kg

Calorific value of fuel, C_f = 5000 kcal/kg

Initial temperature of water, T_1 = 31.5 ^{0}C

Mass of water taken, M_{W1} = 2 kg

Sensible heat of water (Specific heat), S_W =1 kcal/kg

Temperature of boiling water, T_2 = 99.8 ^{0}C

Mass of water remaining, M_{W2} = 1.4198 kg

Mass of water evaporated, M_{W1}-M_{W2} = 2 – 1.41984 = 0.58016 kg

Latent heat of evaporation of water, L = 540 kcal/kg

% of efficiency = (Useful energy output / Energy input) x 100

= {2x1(99.8-31.5) + (0.58 x 540)} / (0.5x5000) x 100

= **17.99 %**

Table 3. Water temperature variation with time	
Time in minutes	Temperature (^{o}C)
0	31.5
1	35
5	65

10	99.8
15	97
20	94

Inference: Concentrator disc seems to be increasing the efficiency of the stove as it forces the flame to concentrate. Slight improvement of efficiency is possible with better outdoor conditions.

TEST-4 (with concentrator disc and riser, on 27/12/2014)

Observations:

1. Firewood details:

   A mixture of size 1.5 cm to 2 cm

   Weight = 0.5 kg

2. Vessel details:

   Type : Aluminium

   Diameter : 22 cm

   Height : 11 cm

3. Temperatures:

   Ambient temperature : 32 ^{0}C

   Temperature of water before heating : 31.8 ^{0}C

   Temperature of boiling water : 99.7 ^{0}C

4. Other details:

   Test started at 02:57 pm using 20 ml of kerosene. Gasification started by 3:02 pm and ended by 3:11 pm. Vessel allowed to cool on the stove itself. Remaining water measured at 4:50 pm and temperature of water then 35^{0}C.

5. Flame details:

   Yellow

6. Smoke details:

   Initial stage - Light Black

   After 4 minutes - No visible smoke

   After 8 minutes - No visible smoke

Efficiency calculations:

Mass of firewood loaded, M_f = 0.5 kg

Calorific value of fuel, C_f = 5000 kcal/kg

Initial temperature of water, T_1 = 31.8 ^{0}C

Mass of water taken, M_{W1} = 2 kg

Sensible heat of water (Specific heat), S_W =1 kcal/kg

Temperature of boiling water, T_2 = 99.7 ^{0}C

Mass of water remaining, M_{W2} = 1.5283 kg

Mass of water evaporated, M_{W1}-M_{W2} = 2 – 1.5283 = 0.4717 kg

Latent heat of evaporation of water, L = 540 kcal/kg

% of efficiency = (Useful energy output / Energy input) x 100

= {2 x 1(99.7-31.8) + (0.4717 x 540)} / (0.5 x 5000) x 100

= **15.62 %**

Table 6. Water temperature variation with time	
Time in minutes	Temperature (^{o}C)
0	31.8
5	40
10	85
20	92
30	82
40	70

Inference: Riser arrangement seemed to be reducing the efficiency as in the indoor experiments conducted at IRTC. It may be because of reduction of flame temperature with height. Emission characteristics of the riser were not tested in the experiment.

STOVE MODEL III

Stove model III has a different air inlet area compared to the other two. The dimensions are as follows:

Air Inlet	Dimensions	Area
Primary air inlet area	0.37 cm dia. hole x 124	13.33 sq.cm
Secondary air inlet area	0.73 cm dia hole x (38+38)	31.808 sq.cm

In this model, the secondary air placed 10 cm above the primary air inlets, which makes a riser of height 9.9 cm above the secondary holes as shown in the figure below.

Outdoor Testing of Stove model III

TEST-1 (on 29/12/2014)

Observations:

1. Firewood details:

   A mixture of size 1.5 cm to 2 cm

   Weight = 0.5 kg

2. Vessel details:

   Type : Aluminium

   Diameter : 22 cm

   Height : 11 cm

3. Temperatures:

   Ambient temperature : 31.5 ^{0}C

   Temperature of water before heating : 31 ^{0}C

   Temperature of boiling water : 99.8 ^{0}C

4. Other details:

   Test started at 12:21 pm using 20 ml of kerosene. Gasification started by 12:26 pm and ended by 12:36 pm. Vessel allowed to cool on the stove itself. Remaining water measured at 02:20 pm and temperature of water then 36^{0}C.

5. Flame details:

   Yellow

6. Smoke details:

   Initial stage - Light Black

   After 4 minutes - No visible smoke

   After 8 minutes - No visible smoke

Efficiency calculations:

Mass of firewood loaded, $M_f = 0.5$ kg

Calorific value of fuel, $C_f = 5000$ kcal/kg

Initial temperature of water, $T_1 = 31^0$C

Mass of water taken, $M_{W1} = 2$ kg

Sensible heat of water (Specific heat), $S_W = 1$ kcal/kg

Temperature of boiling water, $T_2 = 99.8\ ^0$C

Mass of water remaining, $M_{W2} = 1.469$ kg

Mass of water evaporated, $M_{W1}-M_{W2} = 2 - 1.469 = 0.5308$ kg

Latent heat of evaporation of water, L = 540 kcal/kg

% of efficiency = (Useful energy output / Energy input) x 100

= {2 x 1(99.8-31) + (0.5308 x 540)} / (0.5 x 5000) x 100

= **16.96 %**

Table 6. Water temperature variation with time

Time in minutes	Temperature (^{o}C)
0	31
5	40
10	88
20	97
30	91
40	80

Inference: Slight windy conditions resulted in lower efficiency.

TEST-2 (on 29/12/2014)

Observations:

1. Firewood details:

A mixture of size 1.5 cm to 2 cm

Weight = 0.5 kg

2. Vessel details:

Type : Aluminium

Diameter : 22 cm

Height : 11 cm

3. Temperatures:

Ambient temperature : 29.8 ^{0}C

Temperature of water before heating : 30^0C

Temperature of boiling water : 99.7 ^{0}C

4. Other details:

Test started at 02:34 pm using 20 ml of kerosene. Gasification started by 02:37 pm (non-uniform flame was achieved) and ended by 02:49 pm. Vessel allowed to cool on the stove itself. Remaining water measured at 03:50 pm and temperature of water then 48^0C.

5. Flame details:

Yellow

6. Smoke details:

Initial stage - Light Black

After 4 minutes - No visible smoke

After 8 minutes - No visible smoke

Efficiency calculations:

Mass of firewood loaded, $M_f = 0.5$ kg

Calorific value of fuel, $C_f = 5000$ kcal/kg

Initial temperature of water, $T_1 = 30^0$C

Mass of water taken, $M_{W1} = 2$ kg

Sensible heat of water (Specific heat), $S_W = 1$ kcal/kg

Temperature of boiling water, $T_2 = 99.7\ ^0$C

Mass of water remaining, $M_{W2} = 1.4297$ kg

Mass of water evaporated, $M_{W1}-M_{W2} = 2 - 1.4297 = 0.5703$ kg

Latent heat of evaporation of water, L = 540 kcal/kg

% of efficiency = (Useful energy output / Energy input) x 100

= {2 x 1(99.7-30) + (0.5703 x 540)} / (0.5 x 5000) x 100

= **17.89 %**

Table 6. Water temperature variation with time

Time in minutes	Temperature (^{o}C)
0	30
5	42
10	84
20	97
30	86
40	76

TEST-3 (on 29/12/2014)

Observations:

1. Firewood details:

A mixture of size 1.5 cm to 2 cm

Weight = 0.5 kg

2. Vessel details:

Type : Aluminium

Diameter : 22 cm

Height : 11 cm

3. Temperatures:

Ambient temperature : 30.5 ^{0}C

Temperature of water before heating : 29.5 ^{0}C

Temperature of boiling water : 99.8 ^{0}C

4. Other details:

Test started at 04:03 pm using 20 ml of kerosene. Gasification started by 04:05 pm and ended by 04:16 pm. Vessel allowed to cool on the stove itself. Remaining water measured at 05:27 pm and temperature of water then 43.5^{0}C.

5. Flame details:

Yellow

6. Smoke details:

Initial stage - Light Black

After 4 minutes - No visible smoke

After 8 minutes - No visible smoke

Efficiency calculations:

Mass of firewood loaded, M_f = 0.5 kg

Calorific value of fuel, C_f = 5000 kcal/kg

Initial temperature of water, T_1 = 29.5^{0}C

Mass of water taken, M_{W1} = 2 kg

Sensible heat of water (Specific heat), S_W =1 kcal/kg

Temperature of boiling water, T_2 = 99.8 ^{0}C

Mass of water remaining, M_{W2} = 1.4008 kg

Mass of water evaporated, M_{W1}-M_{W2} = 2 – 1.4 = 0.6 kg

Latent heat of evaporation of water, L = 540 kcal/kg

% of efficiency = (Useful energy output / Energy input) x 100

= {2 x 1(99.8-29.5) + (0.6 x 540)} / (0.5 x 5000) x 100

= **18.58 %**

Table 6. Water temperature variation with time	
Time in minutes	Temperature (^{o}C)
0	29.5
5	65
10	99.6
20	93
30	87
40	79

Inference: Improved efficiency due to slightly restricted environment.

SUMMARY

Outdoor Water boiling test of the stove model II produced efficiencies of **14.03%** and **17.52%** on two successive runs. First run produced lower efficiency as the vessel was removed from the stove, soon after the gasification of the fuel stopped while in the second run the water was allowed to cool with the vessel placed over the stove.

Third and fourth run was done to find the effect of concentrator disc and riser on stove performance. With concentrator disc alone an efficiency of **17.99%** was obtained. Which clearly states a concentrator disc can improve a stove's performance, while the riser + Concentrator disc arrangement produced a lower efficiency of **15.62%.** Even though it is difficult to state that a riser decreases stove's efficiency (effect of riser was not done individually), there is enough doubt on its role improving a stoves performance, though it may reduce the emission factors. Lower efficiency may be due to the lower heat of the flame with height increment.

Testing of the third model produced **16.99%, 17.89%** and **18.58%.** The first test produced the least efficiency because it failed to obtain a uniform burning throughout the chamber at the start itself. The third one hit a maximum as I placed the stove in a restricted space.

*The entire tests conducted were based on the procedure explained earlier. Though it is not a standard procedure for testing stove, for its performance and the values may be lesser than those obtained, it's an easy way for comparing the different experiments.

I would like to thank Dr. Paul Anderson, Julien Winter, Kirk Harris and Dr. P V Shouri for their valuable suggestions, time and guidance.

Saloop T S,
M.Tech. Energy Management,
Govt. Model Engineering College,
Thrikkakara, Ernakulam, Kerala, India

Photos of testing:

Test 1 – flame dispersed under wind

Test 2 – Water boiling

Test 3 – Stove with concentrator disc.

Test 4 – With concentrator disc and riser

Test 5,6,7 on stove model III