

EMISSION CONTROL AND FUEL EFFICIENT BY USING ARDUINO BASED SELF-REGULATING BIOMASS STOVE

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ABSTRACT

For the improper combustion of the fuel it produces number of gases like CO₂, CO, SO_x and NO_x. Emission is the main problems while the biomass burning. Due to avoid of emission need to adopt new technologies, in that manner fabricating a Biomass Stove with a design that helps in efficient heat transfer of combustion gases and effective heat distribution of practical stoichiometric air helps in increasing stove efficiency. Usage of an open source electronic component called "ARDUINO" and flue gas sensors, the combustion process of biomass can be actuated and monitored effectively through "ARDUINO" without human interference. Thereby reducing the effect due to toxic vapors that results from incomplete combustion and increases the efficiency of the stove.

Keywords: Arduino, Biomass stove, Emission control, Fuel efficient, Self-regulating stove

I. INTRODUCTION

Reliance on biomass as primary energy source for cooking purpose,[1] Based on work done for WEO-2002, a database of the number of people relying on biomass as their primary fuel for cooking for each country in the WEO developing regions was built up using survey and census data, World Health Organization (WHO) data and direct correspondence with national administrations.

	Total population		Rural		Urban	
	%	million	%	million	%	million
Sub-Saharan Africa	76	575	93	413	58	162
North Africa	3	4	6	4	0.2	0.2
India	69	740	87	663	25	77
China	37	480	55	428	10	52
Indonesia	72	156	95	110	45	46
Rest of Asia	65	489	93	455	35	92
Brazil	13	23	53	16	5	8
Rest of Latin America	23	60	62	59	9	25
Total	52	2 528	83	2 147	23	461

Fig.1 People Relying on Biomass Resources as their Primary Fuel for Cooking, 2004 [1]

Fig.1 shows people relying on Biomass Resources as their primary fuel for cooking ,2004 WEO estimate that over 2.5 billion people, or 52% of the population in developing countries, depend on biomass as their primary fuel for cooking. For over half of these people live in India, China and Indonesia.

1.1 Effects that arise due to biomass based cooking methods [1]

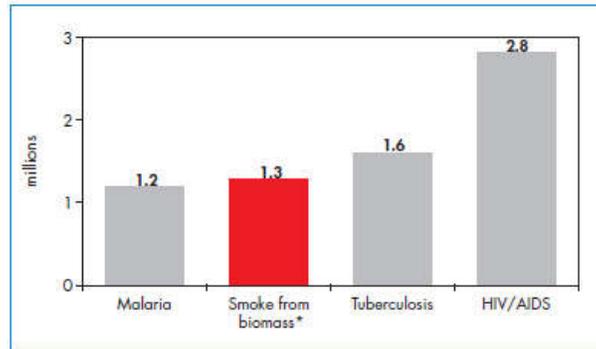


Fig.2 Annual deaths worldwide by cause [1]

Fig.2 shows Annual deaths worldwide by cause. The World Health Organization (WHO) estimates that 1.5 million premature deaths per year are directly attributable to indoor air pollution from the use of solid fuels. That is more than 4000 deaths per day, more than half of them children under five years of age.

Fuelwood, roots, agricultural residues and animal dung all produce high emissions of carbon monoxide, hydrocarbons and particulate matter. Hydrocarbon emissions are highest from the burning of dung for fuel, while particulate emissions are highest from agricultural residues. Women and children suffer most from indoor air pollution because they are traditionally responsible for cooking and other household chores, which involve spending hours by the cooking fire exposed to smoke. Young children are particularly susceptible to disease, which accounts for their predominance in the statistics for premature deaths due to the use of biomass for cooking.

1.2 Concept of Self Regulating Biomass Stove

In order to protect the user from the harmful effects of the exhaust gas that results from incomplete combustion, a microcontroller called Arduino is used to monitor the combustion process and give a feedback to the user about the harmful emission. So enough air is forced to the combustion chamber to ensure required stoichiometric ratio.

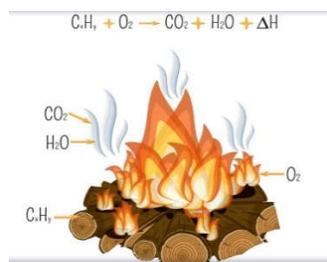


Fig.3 Ideal combustion process

Fig.3 shows the ideal combustion process chemical reaction .In general the hydrocarbon on combustion gives rise to carbon dioxide and water.In addition to its other components are also released, Carbon monoxide, nitrogen, Sulphur. But these gas a colorless, being odorless and toxic in nature.

II. OXYGEN AS A PARAMETER TO ANALYZE CONSTITUENT OF EXHAUST GAS

Oxygen is considered as a parameter to analyze the process because it's the oxygen concentration in stoichiometric air that decides whether the fuel is undergoing complete combustion resulting in the formation of carbon dioxide (CO_2) or incomplete combustion resulting in the formation of carbon dioxide.

2.1 Excess Oxygen

- Practically complete combustion cannot be achieved by stoichiometric air alone. The stoichiometric air must be suitably multiplied with a factor between 2-2.5.
- If more air is pumped in than the actual air required, then along with carbon dioxide and water vapour excess oxygen is discharged.

2.2 Deficient oxygen

- If there is low oxygen supplied then the fuel would burn incompletely with evolution of toxic smoke.
- So instead of forming carbon di-oxide, carbon monoxide might be formed.

2.3 Requirement of an Arduino Uno Microcontroller



Fig.4 Arduino Uno

Fig.4 shows Arduino Uno Microcontroller. Arduino is an open-source electronics platform based on easy-to-use hardware and software. Arduino boards are able to read inputs, process the inputs and give outputs such as activating a motor, turning on LED etc. We can tell the board what to do by sending a set of instruction.

2.4 Utilizing Arduino in Biomass Stove

Arduino is used to monitor the air required for complete combustion using the input signal from various gas sensors sensing exhaust gas. Based on the pre-coded instruction on the above mentioned parameter of taking oxygen as a

measure to figure out the state of combustion process, the arduino varies the speed of the fan to supply sufficient stoichiometric air to ensure complete combustion.

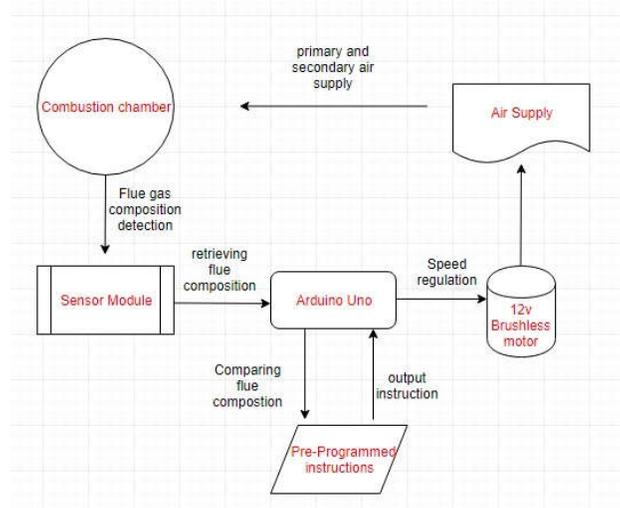


Fig.5 Systematic Representation of Self-Regulating Biomass Stove

Fig.5 shows the systematic representation of a self- regulating Biomass Stove .The flue gases composition is detected by the sensor module consisting of carbon di-oxide, carbon monoxide and smoke sensors respectively. The flue gas composition is retrieved by “Arduino uno” with the help of the a programme based on oxygen as a parameter for evaluation ,the speed of brushless motor is altered thereby supplying adequate air for proper combustion.

2.5 Sensor and accessories used along with Arduino

- Carbon di-oxide sensor
- Carbon monoxide sensor
- Smoke sensor
- 12v brushless motor
- Jumper cables for connection

2.6 Inputs to Arduino

Using Smoke sensor, carbon monoxide and carbon di-oxide sensor the deficient and excess oxygen content, along with toxic components can be detected. This input is retrieved by the Arduino and synchronizes with the code programmed on it.

III. DESIRED ANALYSIS OF FLUE GAS COMPOSITION BY ARDUINO PROGRAMME LOOP

3.1 Deficient oxygen

- The deficient oxygen leads to increased ‘co’ content and reduced ‘co₂’ these individual content is detected with carbon di-oxide and carbon monoxide sensor and toxic smoke is detected through smoke sensor.

- Both the sensors are linked to 'ARDUINO' and through a code programmed on it, necessary excess air flow is maintained by the 'ARDUINO' by regulating the motor speed by varying the motor voltage.
- As a result of which toxic smoke emission can be contained therefore ensuring user friendliness.

3.2 Excess oxygen

- The excess oxygen leads to higher CO_2 content and reduced CO content, but care should be taken to not exceed the theoretical stoichiometric ratio by a greater extent.
- Hence presence of excess oxygen is detected by the smoke and CO sensor.
- Both the sensors are linked to 'ARDUINO' and through a code programmed, necessary air flow is maintained by the 'ARDUINO' by regulating the Brushless motor speed by varying the motor voltage.

IV. FABRICATING A RECYCLED BIO-STOVE

4.1 Fabrication

- Using an Oil Tin can as Outer Combustion Chamber
- Using a Recycled Steel can as Inner combustion Chamber
- 12 v stepper motor
- Sensor Module (mentioned above)



Fig.6.A Outer Combustion chamber Fig.6.B Inner Combustion Chamber

Fig.6.A and Fig 6.B depicts inner and outer combustion chamber made of scrap items using oil tin to make outer combustion chamber and stainless steel can to fabricate the inner combustion chamber. The upper portion of inner combustion chamber consists of holes around its circumference to facilitate air movement (secondary air). The lower portion of outer combustion chamber has holes on it draw in primary air. The larger hole at the center accommodates the draft fan.



Fig.6.C Brushless Motor Fig 6.D grate

Fig.6.C and Fig.6.D depicts 12 volt Brushless motor and grate at the bottom of the inner combustion chamber. The 12 volt stepper motor runs according to the pulse input from Arduino to vary the required speed. The primary air enters the inner combustion chamber through the grate provided at the bottom.



Fig.6.E Assembled Top View

Fig.6.E shows the Assembled Top View of the Recycled Biomass Stove. The Stove incorporates a two way combustion process to facilitate efficient combustion.

V. WORKING PROCEDURE



Fig.7 Work Setup

Fig.7 shows the running work setup of the recycled biomass stove.

Primary air– Is supplied to the fuel mixture along with ignition required for Combustion through a grate provided at the bottom of the inner combustion chamber. Due to Inhomogeneous distribution of air in the stove, stoichiometric air is not sufficient for complete combustion practically. Hence smoke exits from the ignition mixture, before complete combustion. Leading to emission of toxic vapors.

Secondary air– If excess air is supplied to the top of combustion chamber where smoke exits, then the smoke can be heated once more before exit there by ensuring complete. Both primary and secondary air is circulated by a mini fan powered by 12 v stepper motor incorporated within the stove casing. The secondary air is absorbed through the holes over the top circumference of inner chamber. Since it passes along the circumference inner chamber the air gets heated up, helping in further combustion of exit gases leading to a much cleaner exhaust smoke along with complete combustion

5.1 Drawback in a two stage combustion process

Non-homogeneous air distribution within the stoves makes it difficult to determine the actual air required for complete combustion. As a result of which the user is exposed to toxic gases and on only trial and error basis the user can maintain complete combustion of the Biomass.

5.2 Utilizing Arduino to overcome the drawback

An open source platform can easily be coded to sense the exhaust gas composition through sensors as an input source .Based on the pre-programmed instruction that's aimed at achieving complete combustion; the fan speed is varied accordingly. The time lag for each test check is fixed to an average value of the exhaust gas composition in 5 seconds to allow a change on the fan speed for every 20 seconds, by Arduino.

The programme is coded with the idea of taking oxygen as a parameter that decides the amount of carbon di-oxide and carbon mon-oxide formed.

5.3 Programmed Coded To Arduino

```

/*
 * #####
 * #                                     #
 * #                               * # SELF REGULATING BIOMASS-STOVE CODE #
 * #                                     #
 * #####
 *
 * Circuit connections
 * -----
 * CO2 Sensor -> Pin A0
 * CO Sensor  -> Pin A1
 * Motor Control Input -> Pin A2

```

```

* Waterproof Temperature Sensor -> Pin 2
* ESC Output Signal wire -> Pin 9
*
*/
// Waterproof Temperature Sensor
// -----
#include <OneWire.h>
#include <DallasTemperature.h>
// Data wire is plugged into pin 2 on the Arduino
#define ONE_WIRE_BUS 2
OneWire oneWire(ONE_WIRE_BUS); // Setup a oneWire instance to communicate with any OneWire devices (not
just Maxim/Dallas temperature ICs)
DallasTemperature sensors(&oneWire); // Pass our oneWire reference to Dallas Temperature.
// ESC Motor Control
// -----
#include <Servo.h>
Servo ESC1;
int pos = 0; //Sets position variable
void setSpeed(int speed) {
int angle = map(speed, 0, 1023, 30, 154); //angle range 60 -> 154
//The motor will start running when angle is greater than 60
ESC1.write(angle);
}
void setMotorSpeed() {
int speed = analogRead(A2);
setSpeed(speed);
}
// Gas Sensors
// -----
#define co2Sensor A0
#define coSensor A1
int co2average, co2sum = 0;
int coaverage, cosum = 0;
int co2sensorValue;
intcosensorValue;
void getGasValue() { //takes 5 seconds for readings
for(int i=0 ; i<25 ; i++) {

```

```

    co2sensorValue = analogRead(co2Sensor);
    co2sum += co2sensorValue;
    cosensorValue = analogRead(coSensor);
    cosum += cosensorValue;
    delay(200); //takes each reading after 200 msec for 25 times → 5 sec
  }
  co2average = co2sum/10; //It calculates the average of collected sensor readings. Co2average will be calculated
every 5 seconds
  coaverage = cosum/10; //It calculates the average of collected sensor readings. Coaverage will be calculated
every 5 seconds
  Serial.print(co2average);
  Serial.print(", ");
  Serial.print(coaverage);
  Serial.print(", ");
  co2sum = 0;
  cosum = 0;
}
void getTemperature() {
  sensors.requestTemperatures();
  Serial.println(sensors.getTempCByIndex(0)); // Why "byIndex"? You can have more than one IC on the same bus. 0
refers to the first IC on the wire
}
void setup() {
  // Temperature Sensor //
  Serial.begin(9600); //Begin serial communication
  sensors.begin();
  // ESC CONTROL //
  ESC1.attach(9); //Adds ESC to pin 9.
  // Gas Sensors //
  delay(30000); //delay 30 seconds for letting the sensor to heat up
}
void loop() {
  // Gas Sensor //
  getGasValue(); //takes 20 seconds for readings
  // Temperature Sensor //
  getTemperature();
  //----- MESSAGE IS PRINTED IN THE FORMAT: <CO2 value>, <CO value>, <Temperature> -----

```

```
// ESC CONTROL //
for(int I = 0 ; I< 40 ; i++) { // motor speed is controlled for 20 seconds before taking next readings
setMotorSpeed();
delay(500);
}
}
```

VI.RESULT AND DISCUSSIONS ON SELF-REGULATING BIOMASS STOVE

6.1 CASE 1-Free Convection (Combustion chamber completely filled)

Using The Developed Biomass stove without Arduino setup but incorporating sensor module to monitor flue gas composition (Free convection).

Procedure

The inner combustion chamber is filled up to its full capacity and ignition is provided with 10ml kerosene, so that the mixture gets ignited quickly. And the biomass continues to burn under free convection without any external source to provide air for combustion.

Observation

- Water temperature -24.75 degree Celsius
- Room temperature-28 degree Celsius
- Quantity of water -1 liter
- Duration of experiment -9.66 minutes
- Final temperature of water - 60.93 degree Celsius
- Fuel used – wood chip

6.1.1Carbon Di-Oxide versus Time graph

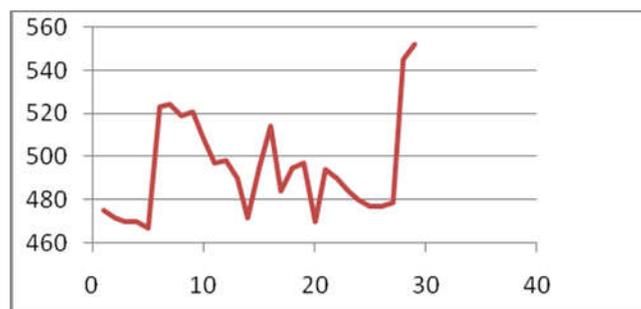


Fig.8 CO₂v/s Time

Note-CO₂ concentration 1 unit =20 ppm

Time 1 unit =.33sec

Inference from graph :The Carbon di oxide sensor takes some time to get heated to show accurate values that's why there is initial low value of CO_2 concentration. But there is no clear pattern to distinguish the nature of the process as there are abnormal spikes.

Reason: Due to non-homogeneous distribution of air in the biomass stove the CO_2 Composition keeps varying according to the availability of air. As a result of which unusual spikes are observed.

6.1.2 Carbon monoxide versus Time graph

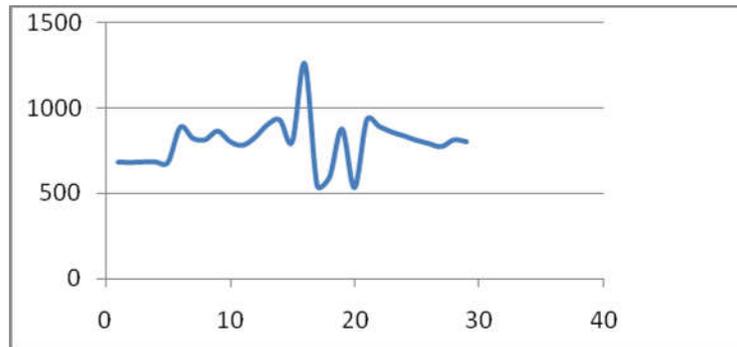


Fig.9 CO v/s Time

Note- CO_2 concentration 1 unit = 20 ppm

Time 1 unit =.33sec

Inference from graph :The Carbon monoxide sensor takes some time to get heated to show accurate values that's why there is initial low value of CO concentration. But there is no clear pattern to distinguish the nature of the process as there are abnormal spikes.

Reason: Due to non-homogeneous distribution of air in the biomass stove the CO Composition keeps varying according to the availability of air. As a result of which unusual spikes are observed.

6.1.3 Temperature versus Time graph

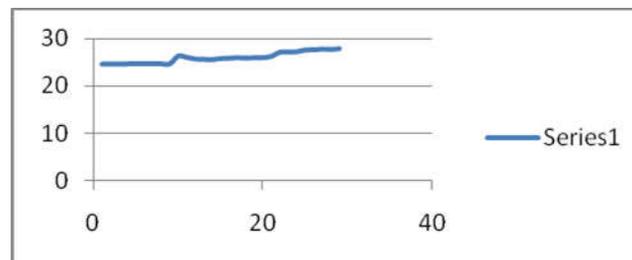


Figure.10 Temperature v/s Time

Note- Time 1 unit =.33 seconds

Inference: The Final and initial temperature difference is $((27.98-24.362) * 10) = 36.18$ degree Celsius rise.

6.2 CASE2- Self-Regulating Arduino Based Forced convection (Combustion chamber completely filled)

Procedure

The inner combustion chamber is filled up to its full capacity and ignition is provided with 10ml kerosene, so that the mixture gets ignited quickly. And the biomass continues to burn under forced convection with external source to provide air for combustion.

Observation

- Initial Water temperature -24.75 degree Celsius
- Room temperature-28 degree Celsius
- Quantity of water -1 liter
- Duration of experiment -9.66 minutes
- Final temperature of water- 69.25 degree Celsius
- Fuel used – wood chi

6.2.1 Carbon Di-Oxide and Carbon monoxide v/s Time graph

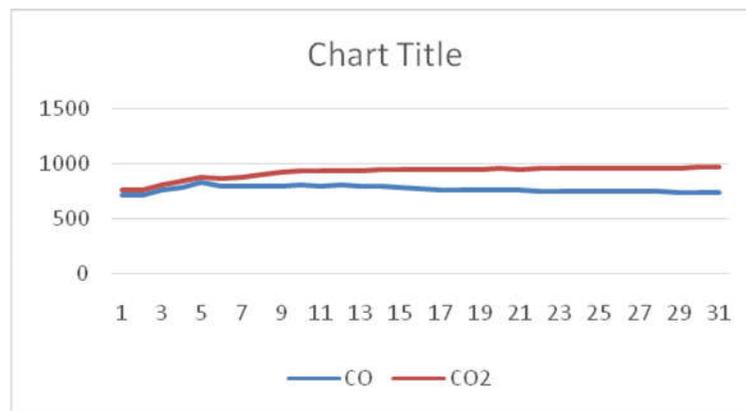


Fig.11 CO₂, CO v/s Time

Note-CO₂, CO concentration 1 unit = 20 ppm

Time 1 unit = .33sec

Inference from graph: Since forced convection takes place right from start the relation between carbon di-oxide and carbon monoxide is well established. Initially the concentration levels are very close gradually the graph between CO and CO₂ widens indicating that more carbon di-oxide is created and the carbon monoxide content is being reduced more or less equally.

Reason: As a result of continuous monitoring of exhaust gases by Arduino through sensor input the speed of motor (fan) is actively regulated, ensuring enough supply of oxygen for converting carbon monoxide formed as a result of incomplete combustion into carbon di-oxide.

6.2.2 Temperature v/s Time graph

Inference: The Final and initial temperature difference is $((24.75-29.2) * 10) = 44.5$ degree Celsius rise.

Reason: Due to adequate supply of air to the combustion chamber greater heat transfer rate has been achieved as a result of which greater heat transfer rate has been achieved.

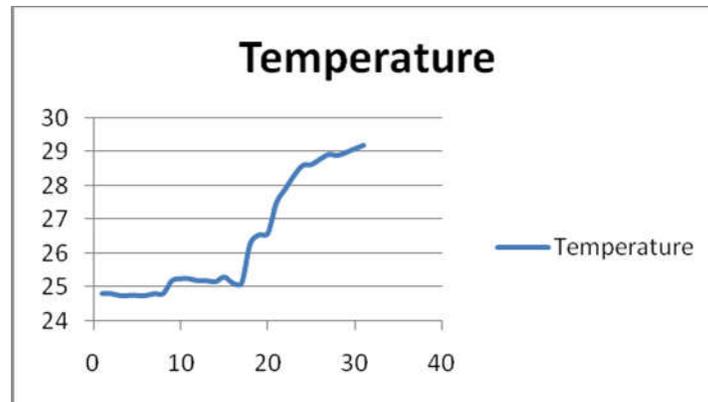


Fig.12 Temperature v/s Time

Note- Time 1 unit =.33 seconds

VII.CONCLUSION

The Heat Transfer rate in free flow convection is lesser than the “Self-regulating arduino based forced convection”, which is evident through difference in temperature of water heated. The toxic gas composition is high in free flow convection when compared to “Self-regulating arduino based forced convection” that has been evident through toxic graph charts. The performance of a free convection Bio-Stove and Self Regulating Biomass stove is studied. The Designed Biomass Stove enables a two stage combustion process. In addition to it, the primary and secondary air is heated helping to increase combustion efficiency. Thereby using a self- regulating Arduino microcontroller the heat transfer rate is increased, hence its more economical and the harms of an exhaust gas is reduced due to active monitoring and regulation of exhaust gas.

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