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LAMPIRAN

LAMPIRAN A. PERHITUNGAN

- **Penentuan *Air-Fuel Ratio* (*AFR*)**

Variasi *AFR* 17,55:1

Diket:

Laju Aliran Udara: 55 LPM

Laju Aliran LPG: 4 SCFH → 4 × 0,47 = 1,88 LPM

ρ_{udara} = 1,2 kg/m^3

ρ_{LPG} = 2 kg/m^3

Ubah laju aliran (LPM) ke m^3/s

$Q_{udara} = 55 \times 1{,}67 \times 10^{-5} = 9{,}19 \times 10^{-4}\ m^3/s$

$Q_{LPG} = 1{,}88 \times 1{,}67 \times 10^{-5} = 3{,}14 \times 10^{-5}\ m^3/s$

Perhitungan Laju Aliran Massa

$\dot{m}_{udara} = Q_{udara} \times \rho_{udara}$

$\dot{m}_{udara} = 9{,}19 \times 10^{-4}\ m^3/s\ \times 1{,}2\ kg/m^3$

$\dot{m}_{udara} = 1{,}1 \times 10^{-3}\ kg/s$

$\dot{m}_{LPG} = Q_{LPG} \times \rho_{LPG}$

$\dot{m}_{LPG} = 3{,}14 \times 10^{-5}\ m^3/s \times 2\ kg/m^3$

$\dot{m}_{udara} = 6{,}3 \times 10^{-5}\ kg/s$

Nilai *AFR*

$$AFR = \frac{\dot{m}_{udara}}{\dot{m}_{LPG}}$$

$$AFR = \frac{1{,}1\times10^{-3}\ kg/s}{6{,}3\times10^{-5}\ kg/s} = \mathbf{17{,}55{:}1}$$

Variasi *AFR* 38,30:1

Diket:

Laju Aliran Udara: 60 LPM

Laju Aliran LPG: 2 SCFH → 2 × 0,47 = 0,94 LPM

ρ_{udara} = 1,2 kg/m^3

ρ_{LPG} = 2 kg/m^3

Ubah laju aliran (LPM) ke m^3/s

$Q_{udara} = 60 \times 1{,}67 \times 10^{-5} = 1{,}002 \times 10^{-3}\ m^3/s$

$Q_{LPG} = 0{,}94 \times 1{,}67 \times 10^{-5} = 1{,}56 \times 10^{-5}\ m^3/s$

Perhitungan Laju Aliran Massa

$\dot{m}_{udara} = Q_{udara} \times \rho_{udara}$

$\dot{m}_{udara} = 1{,}002 \times 10^{-3}\ m^3/s\ \times 1{,}2\ kg/m^3$

$\dot{m}_{udara} = 1{,}2 \times 10^{-3}\ kg/s$

$\dot{m}_{LPG} = Q_{LPG} \times \rho_{LPG}$

$\dot{m}_{LPG} = 1{,}56 \times 10^{-5}\ m^3/s\ \times 2\ kg/m^3$

$\dot{m}_{udara} = 3{,}1 \times 10^{-5}\ kg/s$

Nilai *AFR*

$AFR = \frac{\dot{m}_{udara}}{\dot{m}_{LPG}}$

$AFR = \frac{1{,}2 \times 10^{-3}\ kg/s}{3{,}1 \times 10^{-5}\ kg/s} = \mathbf{38{,}30:1}$

Variasi *AFR* 63,83:1

Diket:

Laju Aliran Udara: 50 LPM

Laju Aliran LPG: 1 SCFH → 1 × 0,47 = 0,47 LPM

ρ_{udara} = 1,2 kg/m^3

ρ_{LPG} = 2 kg/m^3

Ubah laju aliran (LPM) ke m^3/s

$Q_{udara} = 50 \times 1{,}67 \times 10^{-5} = 8{,}4 \times 10^{-4}\ m^3/s$

$Q_{LPG} = 0{,}47 \times 1{,}67 \times 10^{-5} = 7{,}85 \times 10^{-6}\ m^3/s$

Perhitungan Laju Aliran Massa

$\dot{m}_{udara} = Q_{udara} \times \rho_{udara}$

$\dot{m}_{udara} = 8{,}4 \times 10^{-4}\ m^3/s\ \times 1{,}2\ kg/m^3$

$\dot{m}_{udara} = 1{,}0 \times 10^{-3}\ kg/s$

$\dot{m}_{LPG} = Q_{LPG} \times \rho_{LPG}$

$\dot{m}_{LPG} = 7{,}85 \times 10^{-6}\ m^3/s \times 2\ kg/m^3$

$\dot{m}_{udara} = 1{,}6 \times 10^{-5}\ kg/s$

Nilai *AFR*

$AFR = \frac{\dot{m}_{udara}}{\dot{m}_{LPG}}$

$AFR = \frac{1{,}0 \times 10^{-3}\ kg/s}{1{,}6 \times 10^{-5}\ kg/s} = \mathbf{63,83:1}$

Variasi *AFR* 76,60:1

Diket:

Laju Aliran Udara: 60 LPM

Laju Aliran LPG: 1 SCFH → 1 × 0,47 = 0,47 LPM

ρ_{udara} = 1,2 kg/m^3

ρ_{LPG} = 2 kg/m^3

Ubah laju aliran (LPM) ke m^3/s

$Q_{udara} = 60 \times 1{,}67 \times 10^{-5} = 1{,}002 \times 10^{-3}\ m^3/s$

$Q_{LPG} = 0{,}47 \times 1{,}67 \times 10^{-5} = 7{,}85 \times 10^{-6}\ m^3/s$

Perhitungan Laju Aliran Massa

$\dot{m}_{udara} = Q_{udara} \times \rho_{udara}$

$\dot{m}_{udara} = 1{,}002 \times 10^{-3}\ m^3/s\ \times 1{,}2\ kg/m^3$

$\dot{m}_{udara} = 1{,}2 \times 10^{-3}\ kg/s$

$\dot{m}_{LPG} = Q_{LPG} \times \rho_{LPG}$

$\dot{m}_{LPG} = 7{,}85 \times 10^{-6}\ m^3/s \times 2\ kg/m^3$

$\dot{m}_{udara} = 1{,}6 \times 10^{-5}\ kg/s$

Nilai *AFR*

$AFR = \frac{\dot{m}_{udara}}{\dot{m}_{LPG}}$

$AFR = \frac{1,2\times10^{-3}\ kg/s}{1,6\times10^{-5}\ kg/s} = \mathbf{76,60:1}$

- **Perhitungan *Burning Rate***

Variasi *AFR* 17,55:1

Diket:

Volume Biomassa yang Terbakar: 10900 ml

Waktu Proses: 530 $detik \rightarrow 8,33\ menit$

$\rho = 0,18\ g/cm^3$

Massa Biomassa:

$m = V \times \rho$

$m = 10900\ ml \times 0,18\ g/cm^3$

$m = 1962\ g$

Burning Rate

$BR = \frac{m}{t}$

$BR = \frac{1962\ g}{8,33\ menit}$

$\mathbf{BR = 235,53\ g/min}$

Variasi *AFR* 38,30:1

Diket:

Volume Biomassa yang Terbakar: 11700 ml

Waktu Proses: 542 $detik \rightarrow 9,03\ menit$

$\rho = 0,18\ g/cm^3$

Massa Biomassa:

$m = V \times \rho$

$m = 11700\ ml \times 0,18\ g/cm^3$

$m = 2106\ g$

Burning Rate

$BR = \frac{m}{t}$

$BR = \frac{2106\ g}{9{,}03\ menit}$

$\boldsymbol{BR = 233{,}22\ g/min}$

Variasi *AFR* 63,83:1

Diket:

Volume Biomassa yang Terbakar: 15700 ml

Waktu Proses: $683\ detik \rightarrow 11{,}38\ menit$

$\rho = 0{,}18\ g/cm^3$

Massa Biomassa:

$m = V \times \rho$

$m = 15700\ ml \times 0{,}18\ g/cm^3$

$m = 2826\ g$

Burning Rate

$BR = \frac{m}{t}$

$BR = \frac{2826\ g}{11{,}38\ menit}$

$\boldsymbol{BR = 248{,}33\ g/min}$

Variasi *AFR* 76,60:1

Diket:

Volume Biomassa yang Terbakar: 18100 ml

Waktu Proses: $740\ detik \rightarrow 12{,}33\ menit$

$\rho = 0{,}18\ g/cm^3$

Massa Biomassa:

$m = V \times \rho$

$m = 18100\ ml \times 0{,}18\ g/cm^3$

$m = 3258\ g$

Burning Rate

$$BR = \frac{m}{t}$$

$$BR = \frac{3258\ g}{12{,}33\ menit}$$

$$\boldsymbol{BR = 264{,}23\ g/min}$$

LAMPIRAN B. CODING PROGRAM *AUTOFLOW*

```
#include <Servo.h>

Servo gasFlowmeter;    // Servo 1 (180°) Pin 9
Servo gasValve;        // Servo 2 (180°) Pin 10
Servo airFlowmeter;    // Servo 3 (360°) Pin 11

const byte PIN_GASFLOW  = 9;
const byte PIN_GASVALVE = 10;
const byte PIN_AIRFLOW  = 11;

void printMenu() {

  Serial.println();
  Serial.println("===== GASIFICATION TESTER =====");
  Serial.println();

  Serial.println("Flowmeter Gas:");
  Serial.println("GASFLOW 90");

  Serial.println();
  Serial.println("Gas Valve:");
  Serial.println("GASVALVE 180");

  Serial.println();
```

```
  Serial.println("Flowmeter Udara:");
  Serial.println("AIRFLOW 2000");
  Serial.println("AIRFLOW -2000");

  Serial.println();
  Serial.println("===============================");
}

void setup() {

  Serial.begin(9600);

  gasFlowmeter.attach(PIN_GASFLOW);
  gasValve.attach(PIN_GASVALVE);
  airFlowmeter.attach(PIN_AIRFLOW);

  airFlowmeter.write(90); // stop servo 360

  printMenu();
}

void loop() {

  if (Serial.available()) {

    String cmd = Serial.readStringUntil('\n');
    cmd.trim();

    int spasi = cmd.indexOf(' ');
```

```
    if (spasi < 0) {
      Serial.println("Format salah!");
      return;
    }

    String device = cmd.substring(0, spasi);
    int nilai = cmd.substring(spasi + 1).toInt();

    device.toUpperCase();

    // ==========================
    // FLOWMETER GAS
    // ==========================
    if (device == "GASFLOW") {

  if (nilai >= 0 && nilai <= 180) {
    gasFlowmeter.attach(PIN_GASFLOW);
    gasFlowmeter.write(nilai);
    delay(500);   // tunggu servo mencapai posisi
    gasFlowmeter.detach();

    Serial.print("Flowmeter Gas -> ");
    Serial.print(nilai);
    Serial.println(" deg (PWM OFF)");
  }
  else {
    Serial.println("Sudut harus 0-180");
  }
}
```

```
    // ==========================
    // GAS VALVE
    // ==========================
    else if (device == "GASVALVE") {

  if (nilai >= 0 && nilai <= 180) {

    gasValve.attach(PIN_GASVALVE);
    gasValve.write(nilai);
    delay(500);   // tunggu servo mencapai posisi
    gasValve.detach();

    Serial.print("Gas Valve -> ");
    Serial.print(nilai);
    Serial.println(" deg (PWM OFF)");
  }
  else {
    Serial.println("Sudut harus 0-180");
  }
}

    // ==========================
    // FLOWMETER UDARA
    // ==========================
    else if (device == "AIRFLOW") {

      if (nilai > 0) {

        Serial.print("Flowmeter Udara maju ");
        Serial.print(nilai);
```

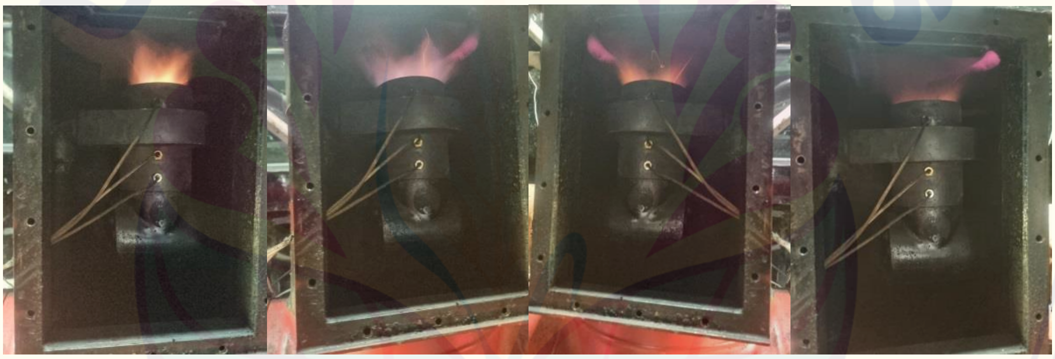
```
          Serial.println(" ms");

          airFlowmeter.write(180);
          delay(nilai);
        }
        else if (nilai < 0) {

          Serial.print("Flowmeter Udara mundur ");
          Serial.print(abs(nilai));
          Serial.println(" ms");

          airFlowmeter.write(0);
          delay(abs(nilai));
        }
        airFlowmeter.write(90);
      }

      else {

        Serial.println("Perintah tidak dikenal!");
      }
    }
  }
```

LAMPIRAN C. GAMBAR HASIL PENELITIAN

Variasi Laju Aliran Udara dan LPG (a) 17,55:1, (b) 38,30:1, (c) 63,83:1, dan (d) 76,60:1

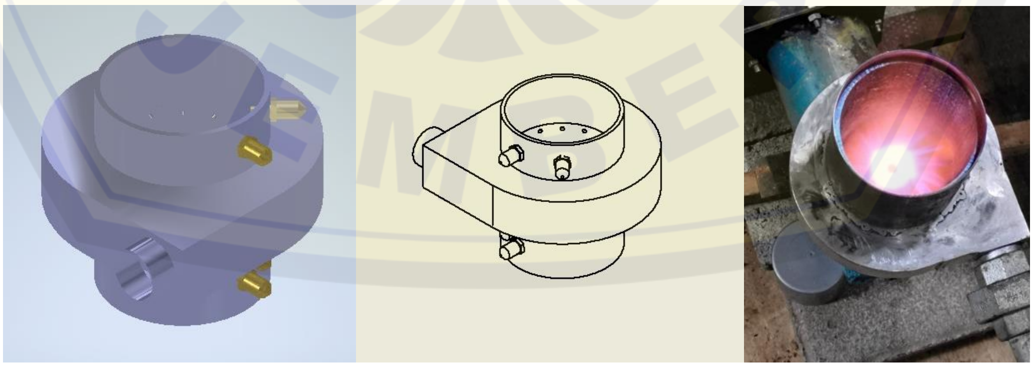
(a) (b) (c) (d)

Gambar Nyala Api pada *Burner Chamber*:



(a) (b) (c) (d)

Desain *Burner Chamber* / *Bed* Gasifikasi:



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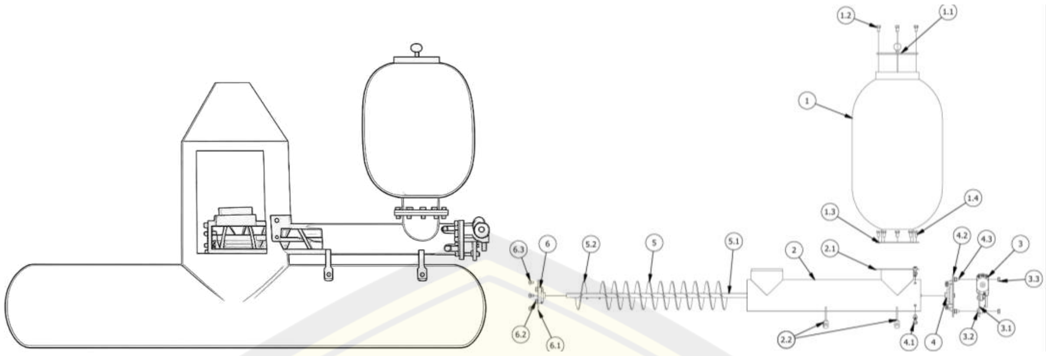
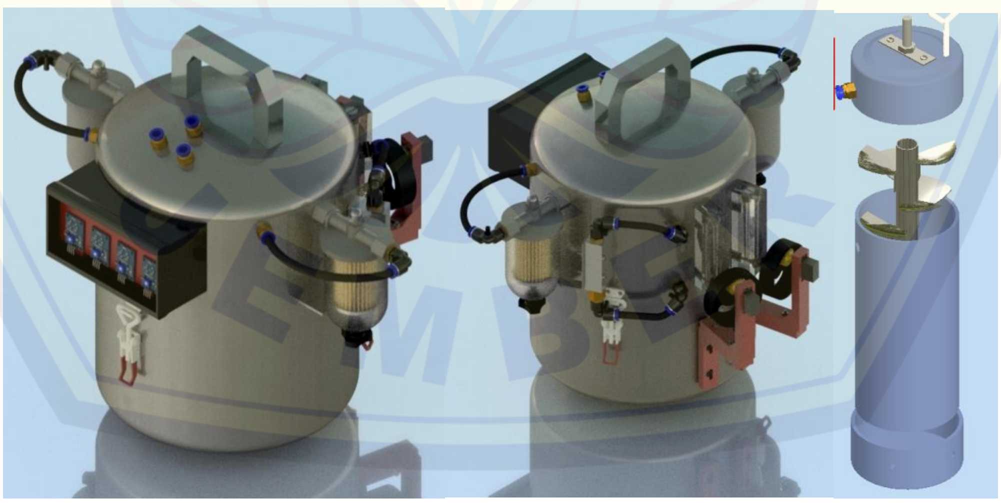
Desain *Screw Feeding* dan Reaktor Gasifikasi:



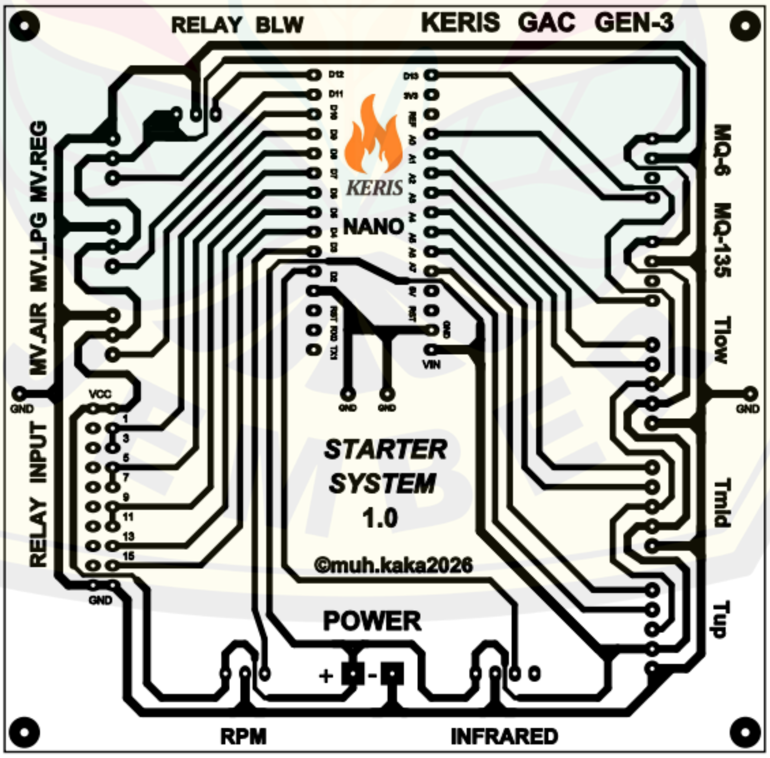
Desain *Gas Analyzer* untuk Pengenceran *Syngas*:



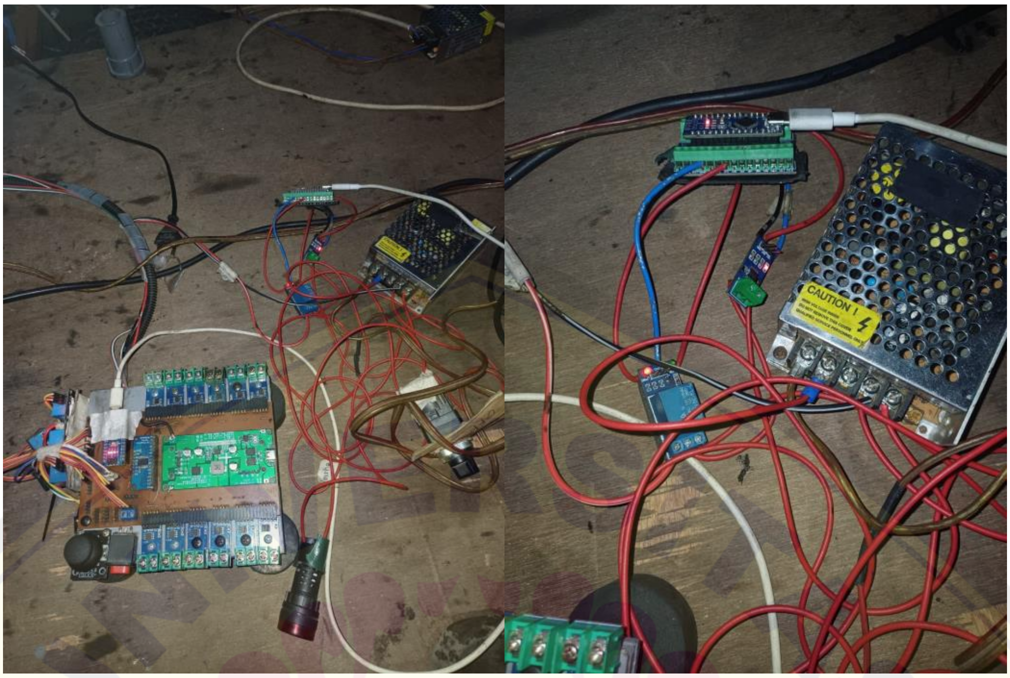
Pengukuran Densitas Biomassa:

Hygrometer Biomassa:

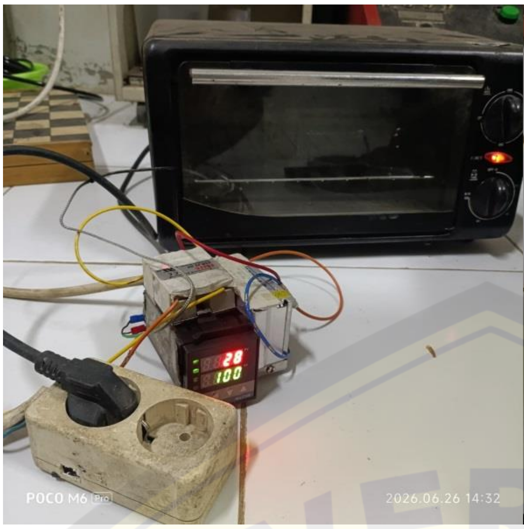
PCB Board sebagai alat instrumentasi *autoflow*:

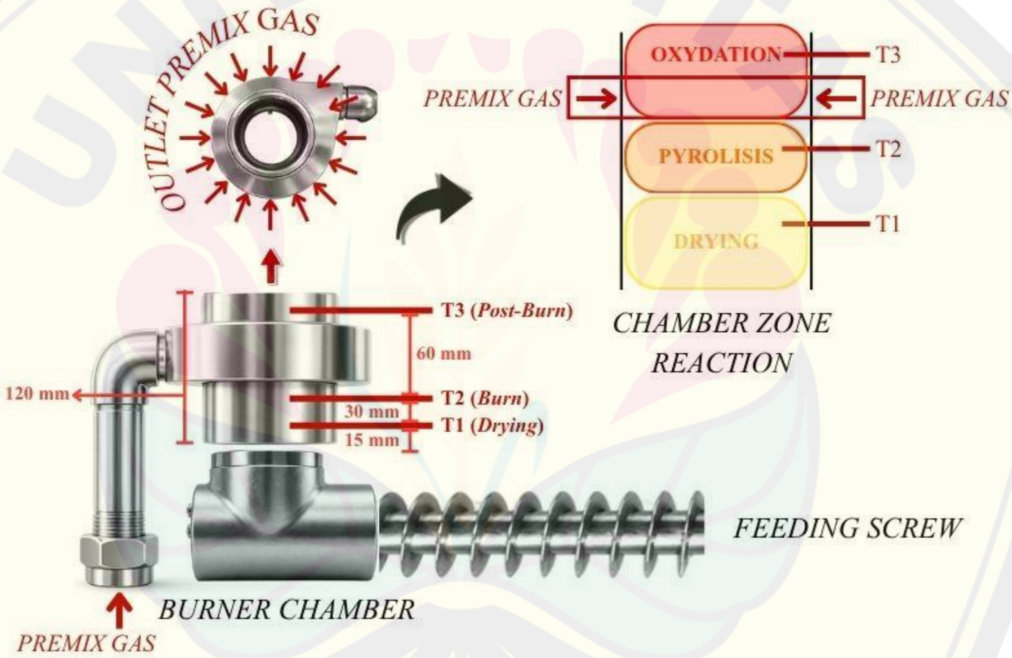


Instrumenyasi *Feeding System*:



Proses Persiapan Biomassa (Pengayaan, Penjemuran, dan Pengovenan):





Simbol	Keterangan
T_1	*Thermocouple* 1 (Titik proses pengeringan)
T_2	*Thermocouple* 2 (Titik proses pembakaran)
T_3	*Thermocouple* 3 (Titik proses pasca pembakaran)

Spesifikasi *Thermocouple*	
Tube Diameter	Min 1 mm
K Type	0 – 1250 °C
Spring Length	70 mm
Wiring Terminal	2 *Wire* (K/JE/T)
Stainless Steel Material	*Default* 304 *Stainless Steel*, *Customized* 2520/3039/316

SENSOR *MAX6675*

Model	MAX6675
Sensor Type	Thermocouple to Digital Converter
Standard Encapsulation	SOIC-8 (IC Package)
Target Measurement	Temperature (K-Type Thermocouple)
Measurement Range	0°C to +1024°C

Spesifikasi Kompresor

Merk : RYU RCP 250-1

Voltase : 220V / 50 Hz

Horse Power: 2,5 HP

Daya listrik : 1900 watt

Kapasitas Tangki: 50 Liter

Kapasitas Aliran Udara: 203 L/menit

Kapasitas Tekanan: 8 Bar

Spesifikasi *Hygrometer*

Simbol	**Keterangan**
MC 1	*Hygrometer* pengukur kelembaban udara luar
MC 2	*Hygrometer* pengukur kelembaban udara masuk

Ukuran Kelembaban (RH)	10% - 99%, resolusi 1%, akurasi +/- 5%
Ukuran Temperatur (°C)	-50°C – 70°C, resolusi 0.1°C, akurasi +/- 1°C
Tegangan Operasi	1.5 V, buah baterai kancing LR44
Dimensi	48 mm x 28,6 mm x 15,2 mm

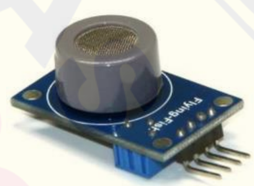
Spesifikasi *MQ-Series*

***MQ*-4**

Model	MQ-4
Sensor Type	Semiconductor
Standard Encapsulation	Bakelite, Metal cap
Target Gas	Methane
Detection range	300～10000ppm(CH_4)

***MQ*-7**

Model	MQ-7
Sensor Type	Semiconductor
Standard Encapsulation	Plastic cap
Target Gas	carbon monoxide
Detection range	10～500ppm CO



***MQ*-8**

Model	MQ-8
Sensor Type	Semiconductor
Standard Encapsulation	Bakelite, Metal cap
Target Gas	Hydrogen
Detection range	100～1000ppm(H_2 gas)

Pengenceran Gas menggunakan *Mixing Chamber* dengan Perbandingan 1:100

Tata cara pengambilan data *syngas*:

1. Mengkalibrasi sensor *MQ-Series* dengan udara bersih sekitar +- 4 jam.
2. Persiapkan peralatan seperti *chamber*, kompresor dan program pembacaan *syngas*.
3. Tunggu sampai temperatur pirolisis.
4. Hidupkan kompresor dan alirkan udara kompresor ke *chamber* melalui *flowmeter*.
5. Alirkan *syngas* melalui *flowmeter*.
6. Atur *flowmeter* udara kompresor dan *flowmeter syngas* dengan perbandingan 1:100 (ex: *flowmeter* 1 LPM *syngas* berbanding udara 100 LPM).
7. Data kandungan *syngas* keluar dalam bentuk ppm dan dikonversi ke persen.

Prosedur Pengambilan Data