Effect of Temperature and Steam to Biomass ratio on NO and SO_2 Formation in Palm Kernel Shell Catalytic Steam Gasification with In-situ CO_2 Adsorption

The 2nd World Sustainability Forum

1 – 30 November 2012

Zakir Khan, Suzana Yusup, and Murni Melati Ahmad
Chemical Engineering Department, University Teknologi PETRONAS,
Tronoh, Perak, Malaysia

Chemical Engineering

Inspiring Potential · Generating Futures

Chemical Engineering
Inspiring Potential·Generating Futures

UNIVERSITI TEKNOLOGI PETRONAS

UNIVERSITI TEKNOLOGI PETRONAS

Chemical Engineering
Inspiring Potential·Generating Futures

UNIVERSITI TEKNOLOGI PETRONAS

UNIVERSITI TEKNOLOGI PETRONAS

Centre of Biofuel and Biochemical Research (CBBR)

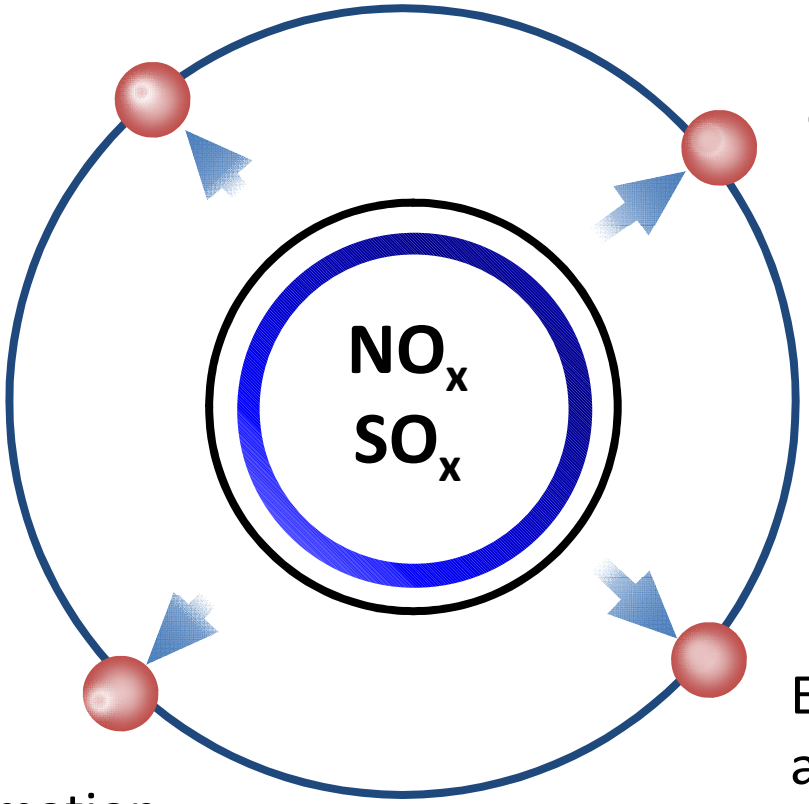
PETRONAS Ionic Liquids Center

Chemical Engineering
Inspiring Potential·Generating Futures

UNIVERSITI TEKNOLOGI PETRONAS

Motivation

Effect on human health



Effect on aquatic and ecosystem

Acid rain formation

Effect on crops and infrastructure

Dhalan et al. (2008)

Chemical Engineering
Inspiring Potential·Generating Futures

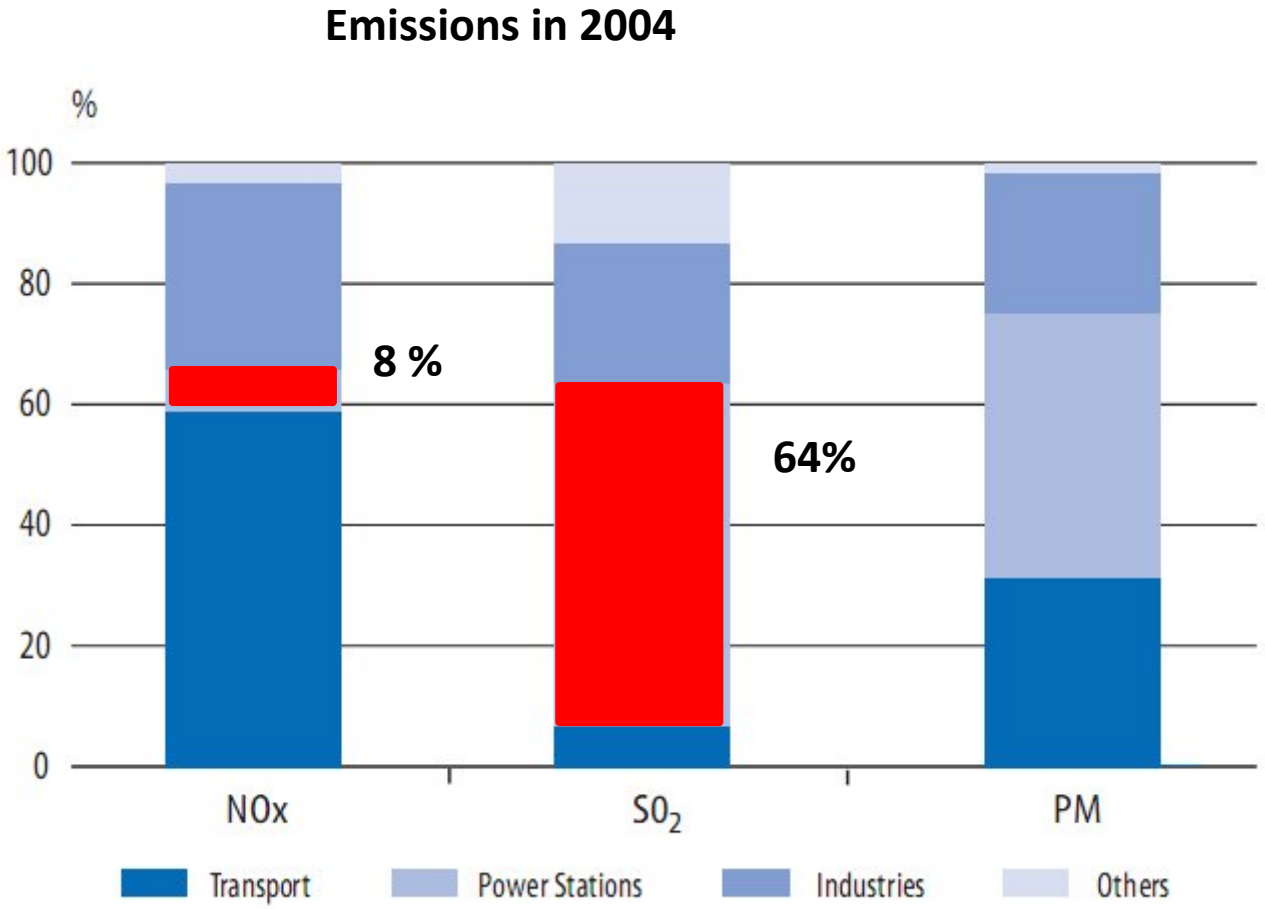
NO_X and SO_x Formation

UNIVERSITI TEKNOLOGI PETRONAS

- Inherent Nitrogen and Sulfur in biomass convert to NO and SO
- NO and SO further convert to NO_2 and SO_2 if excess oxidizing agent (oxygen)is available

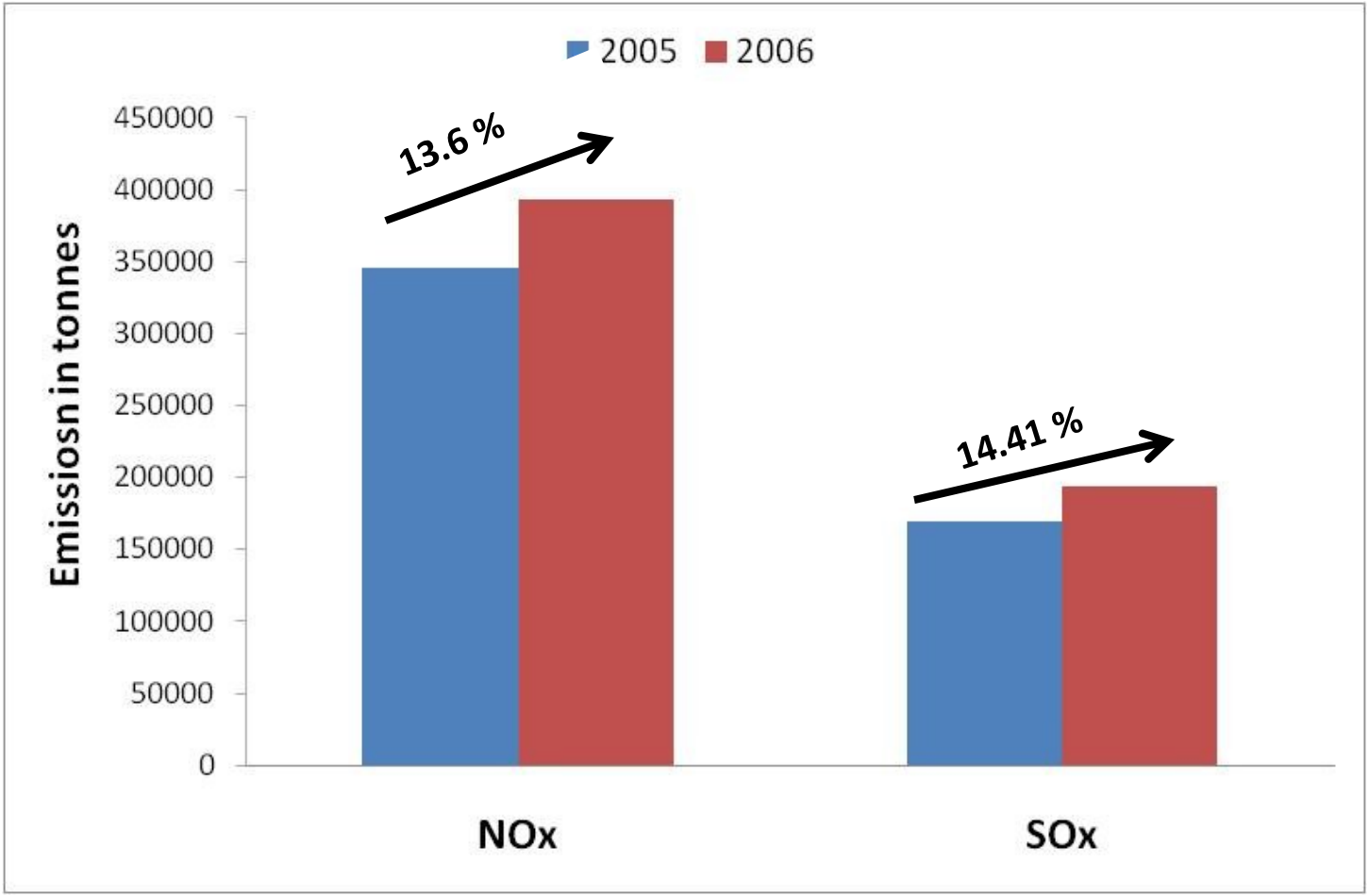
NO and SO_2 emissions are more critical in coal combustion and gasification due to high N and S content

Malayisa-NO_x and SO_x Sources



Asian Development Bank 2006

Malaysia-NO_x and SO_x Emissions



Taib et al. (2009)

Chemical Engineering
Inspiring Potential·Generating Futures

Present Study

UNIVERSITI TEKNOLOGI PETRONAS

Effect of Temperature and steam to biomass ratio

- NO formation
- SO_2 formation

- Comparative study with biomass based power plants

Chemical Engineering
Inspiring Potential·Generating Futures

Literature Review

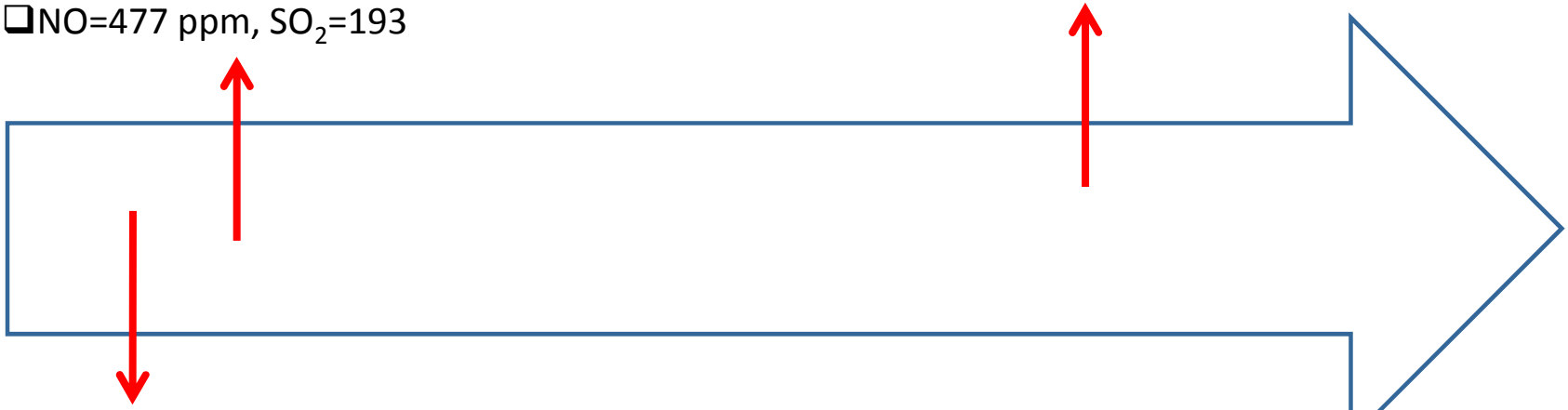
UNIVERSITI TEKNOLOGI PETRONAS

Patel et al. (2001)

- **Poultry litter** and coal co-firing steam gasification (
- T=843 °C (Fixed bed gasifier)
- NO=477 ppm, SO_2=193

Sethuraman et al. (2010)

- **Wood and Corn** air gasification
- T= 815 °C
- NO=



Miles et al. (2005)

- **Swine** and **turkey litter** mixture coal co-firing combustion using CaO
- T=720 °C
- NO_x=10-50 ppm, 0-25 ppm

Present study

- **NO and SO_2 formation from biomass catalytic steam gasification with CO_2 adsorbent**
- **Temperature 600-750 °C**

Chemical Engineering
Inspiring Potential·Generating Futures

Biomass Sample Preparation

UNIVERSITI TEKNOLOGI PETRONAS

Palm kernel shell

- Obtained from My 4-Seasons International Sdn. Bhd.
- Particle diameter range 0.1-4 mm
- Sieved to particle size of 1.0-2.0 mm

Chemical Engineering
Inspiring Potential·Generating Futures

Palm Kernel Shell Properties

UNIVERSITI TEKNOLOGI PETRONAS

Analysis	**Wt% (dry basis)**
Moisture	9.61
Volatiles	80.92
Ash	4.31
Fixed Carbon (by diff.)	14.67
C	49.74
H	5.68
N	1.02
S	0.27
O (by diff.)	43.36

Chemical Engineering
Inspiring Potential·Generating Futures

Catalyst and Adsorbent Preparation

UNIVERSITI TEKNOLOGI PETRONAS

Catalyst

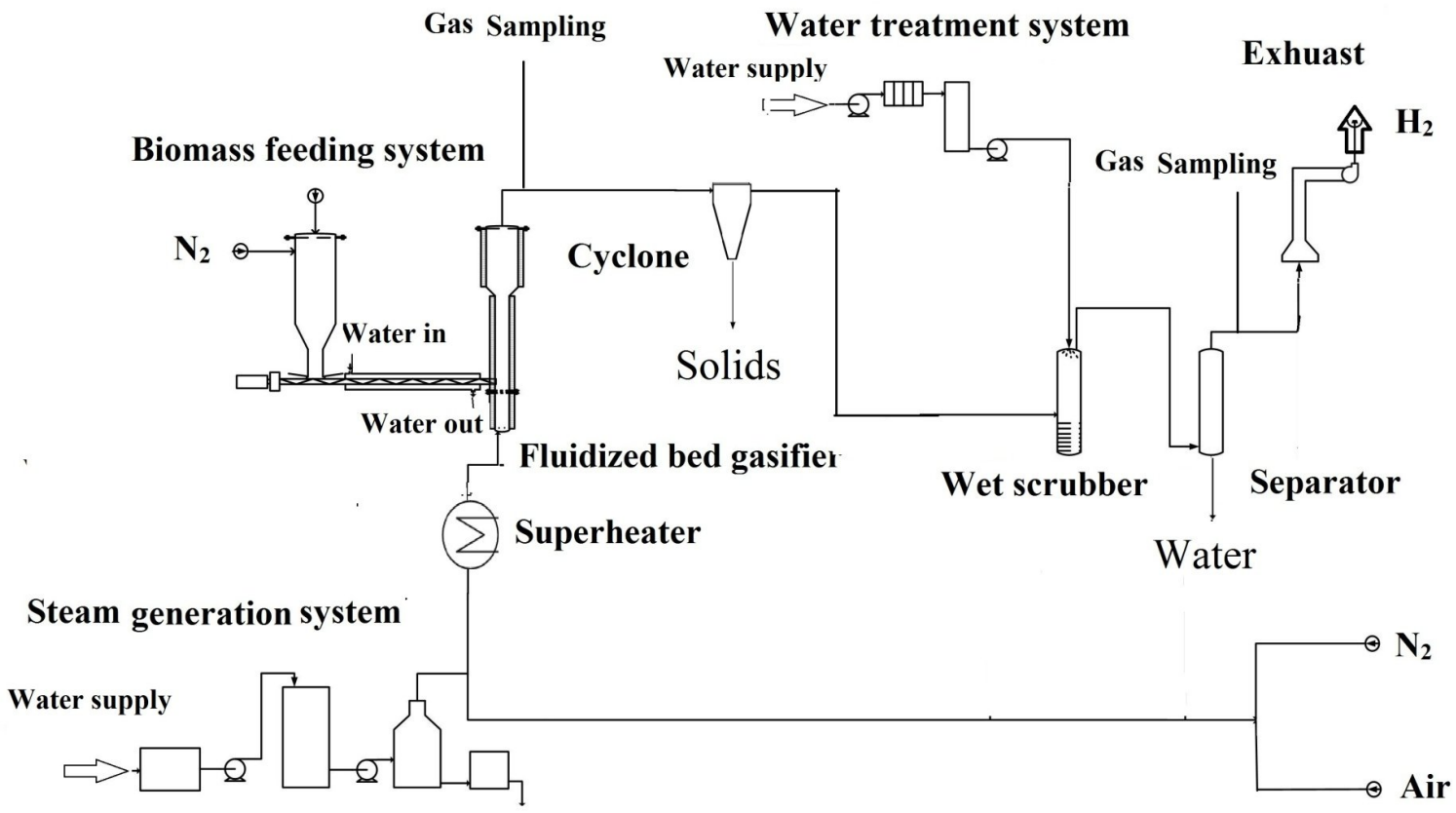
- Ni powder used as commercial catalyst
- Purchased from Merck Chemicals
- Particle diameter ~ 10µm

Adsorbent

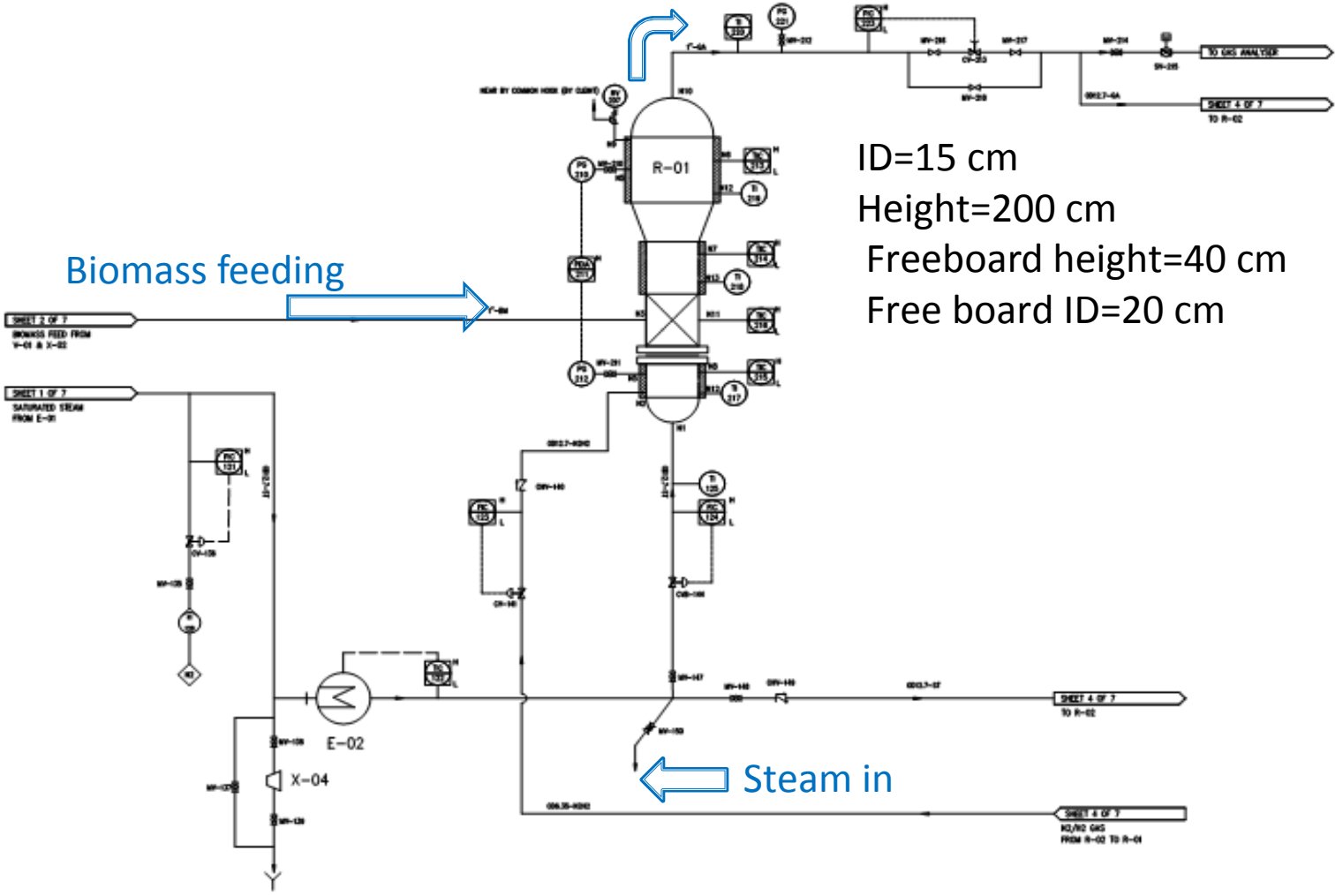
- Purchased from Universal Lime Sdn. Bhd
- Grinded and sieved to particle size of 150-250 µm

Quicklime	
Particle density	3053 Kg/m^3
Bulk density	1047 Kg/m^3

Experimental Set Up



Fluidized Bed Gasifier



ID=15 cm
Height=200 cm
Freeboard height=40 cm
Free board ID=20 cm

Khan et al .(2012) [Unpublished work]

Chemical Engineering
Inspiring Potential·Generating Futures

Operating Conditions

UNIVERSITI TEKNOLOGI PETRONAS

Parameter	Values
Biomass flow rate (kg/h)	1.35
Fluidized bed temperature (°C)	600, 675, 750
Pressure (atm)	1
Steam to biomass ratio (wt/wt)	1.5, 2.0, 2.5
Catalyst to biomass ratio (wt/wt)	0.1
Adsorbent to biomass ratio (wt/wt)	1.0

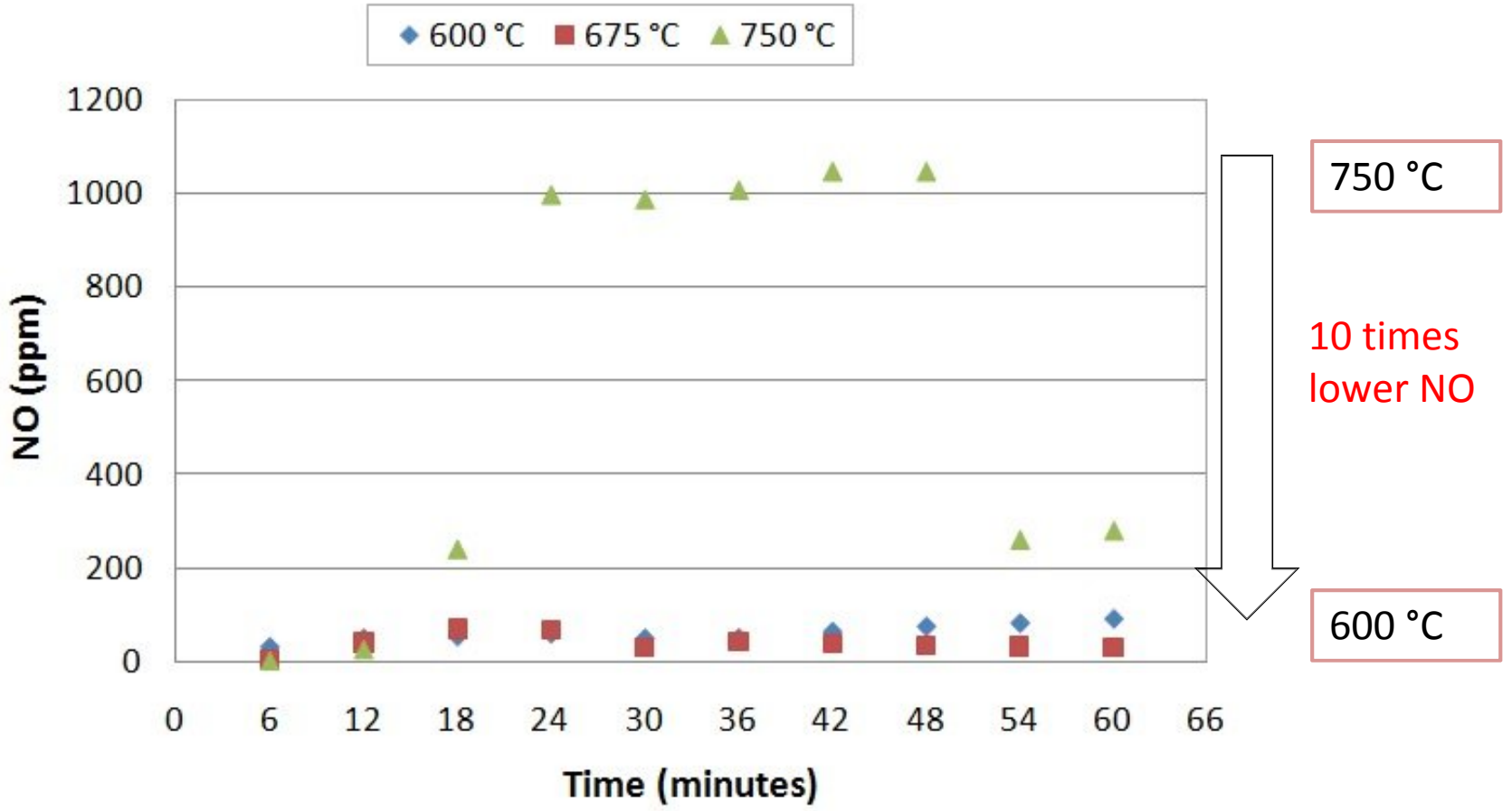
Chemical Engineering
Inspiring Potential·Generating Futures

Experimental Procedure

UNIVERSITI TEKNOLOGI PETRONAS

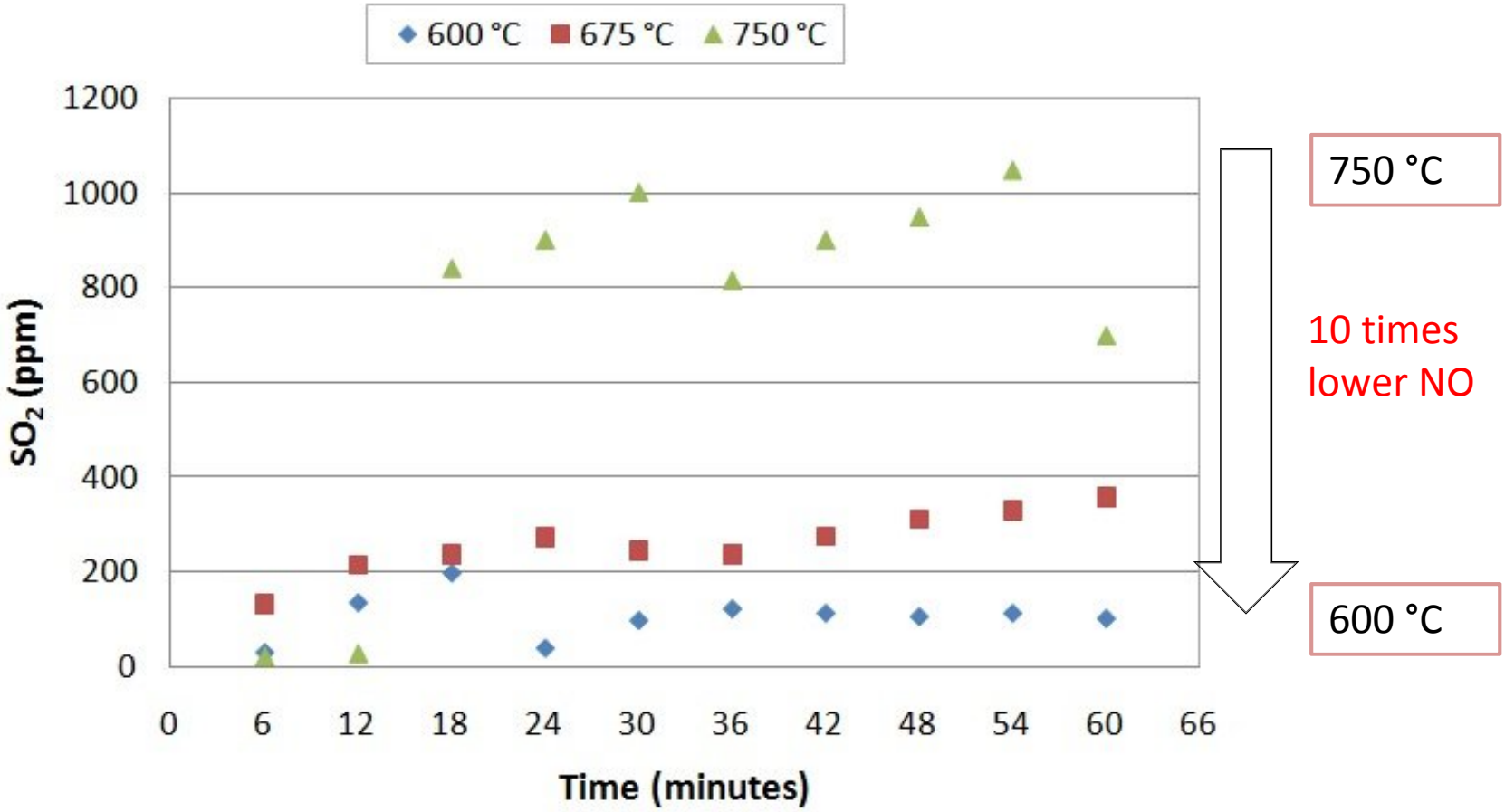
- Fluidized bed gasifier with adsorbent heated to their desired temperature
- Superheated steam introduced to fluidized bed gasifier at 300 °C from superheater
- Biomass+ catalyst is introduced when reactor temperature is stabilized
- Air is purged into the system after gasification experiment to combust the solid residue remaining in the system to calculate char
- Each experiments lasted for 60 minutes

NO Formation-Effect of Temperature



Chemical Engineering
Inspiring Potential·Generating Futures

SO_2 Formation-Effect of Temperature



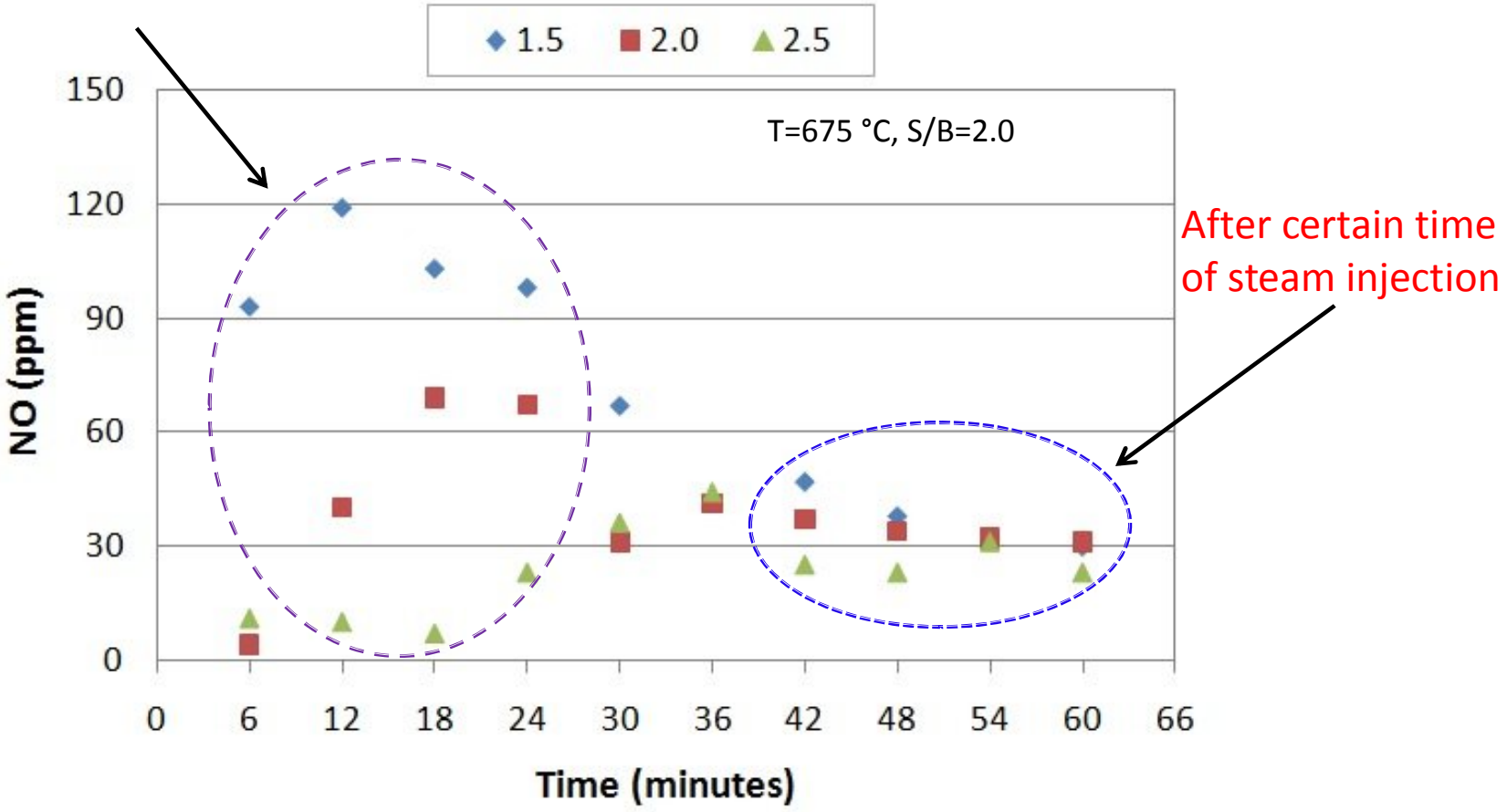
Chemical Engineering
Inspiring Potential·Generating Futures

NO Formation-Effect of Steam to Biomass Ratio

Chemical Engineering
Inspiring Potential·Generating Futures

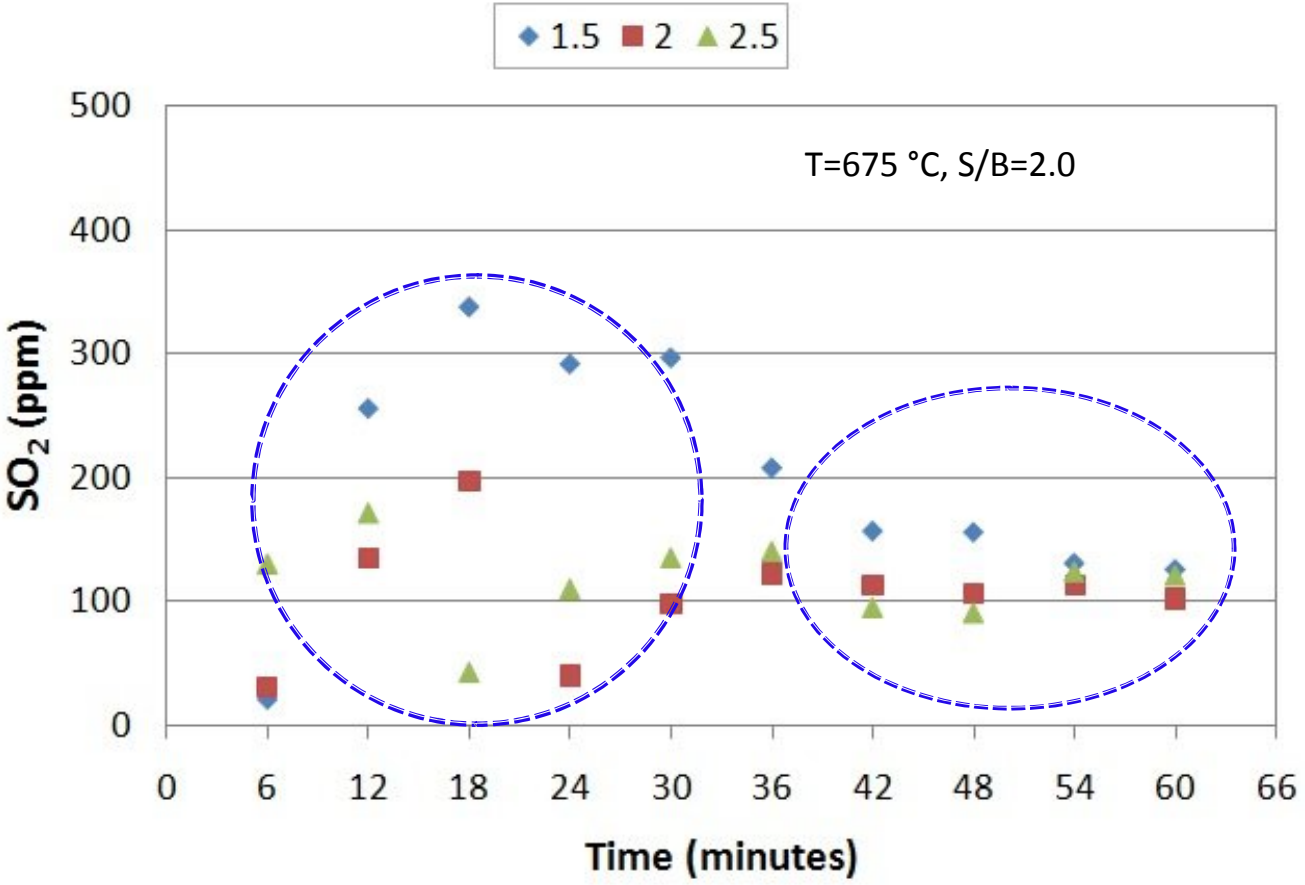
UNIVERSITI TEKNOLOGI PETRONAS

High amount of steam produce oxygen deficient environment



After certain time of steam injection

SO_2 Formation-Effect of Steam to Biomass Ratio



Chemical Engineering
Inspiring Potential·Generating Futures

UNIVERSITI TEKNOLOGI PETRONAS

Chemical Engineering
Inspiring Potential·Generating Futures

Comparative Study

UNIVERSITI TEKNOLOGI PETRONAS

Parameters	Current study	Sethuraman et al. (2010)	Ciferno et al. (2002)		Patel et al. (2001)
Reactor	FB[a]	FB[a]	FB[a] (MTCI)[b]	FB[a] (Sorfresid)[c]	FixB[d]
Biomass	Palm kernel shell	Wood	Pulp sludge	Municipal solid waste	Wood
Gasification agent	Steam	Air	Steam	Air	Steam
Temperature (°C)	675	815	790-815	1300-1400	843
Pressure (atm)	1.0	1	1	1	1
Steam/biomass	2.5	NA	-	-	-
Sorbent/biomass	1.0	1	-	-	-
Catalyst/biomass	0.1	NA	NA	NA	NA
N content (wt%)	1.02	0.14	-	2.3	3.75
S content (wt %)	0.27	-	-	0.3	0.64
NO (ppm)	30	215	25	120	477
SO_2 (ppm)	110	NA	9[e]	79[e]	193

[a]Fluidized bed , [b] Manufacturing and technological conversion international , [c] Sorfresid/caliqua technologies, [d] Fixed bed , [e] SO_x,
"-" shows unknown or not reported[NA] not applicable

Chemical Engineering
Inspiring Potential·Generating Futures

Acknowledgement

UNIVERSITI TEKNOLOGI PETRONAS

Universiti Teknologi PETRONAS

UNIVERSITI TEKNOLOGI PETRONAS

Chemical Engineering
Inspiring Potential · Generating Futures

UNIVERSITI
TEKNOLOGI
PETRONAS

Thank You