Thermal Analysis Of Solid Waste Gasifier-combustor

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Abstract

The increase of municipal solid waste generated in Malaysia has become a critical issue. In year 2001, the amount of solid waste produced in Malaysia is 16,247 tons per day and the rate is continue increasing until today. Besides, landfills are slowly being used up and land for landfill will be scrace mainly due to the increase of population and rapid development of the country.

The gasification-combustion technology is an efficient method to be introduced in order to overcome the excessive amount of municipal solid waste generated in the country. It is a two-step approach of combustion process which is known as primary process (gasification) and secondary process (combustion), basically to ensure all the solid waste loaded into the gasifier-combustor chambers is completely burnt with an excess air supply and the complete combustion process at the secondary stage will lead to a clean flue gas flowing out to the environment. The key operating condition of the system is the thermal management of both gasifier and combustor. Temperature inside the gasifier chamber must be controlled at a range of 800^{0}C – 1000^{0}C and the producer gas must be completely burnt inside the combustor chamber at the temperature of 1000^{0}C as to ensure a proper flow induction of producer gas from gasifier to combustor chamber, an efficient burnout of the solid waste with minimum fly-ash build up and a clean, smoke less flue gas flows out to the environment with CO level which is less than 100ppm.

The objectives of the system are to reduce the volume of domestic waste (kitchen waste, agricultural waste and garden waste) which has contributed about 70% of a total municipal solid waste generated in the country, to protect the environment from harmful air borne particulates/gases throughout the gasification-combustion process and to provide useful by products in the form of hot water, hot air or steam to the users for various purposes. Hence, this paper presents the process characterization of the system which is known as domestic solid waste gasifier-combustor, basically to study the process behaviour and to achieve the desired operating conditions for the system.

Keywords : Solid waste gasifier-combustor, Air borne particulates/gases, Process characterization

1. Introduction

Solid waste which is produced by residents in all local authority areas is getting more and more. Averagely, each Malaysian produced about 0.8 kg of waste everyday (Jaringan Kerajaan Tempatan, 1999). If considering urban residents, the amount are much more because they produce waste about 1.5 kg per capita daily. Research that has been made by JICA (Japanese International Cooperation Agency) in 1998, indicates that the number of solid waste that was produced in Peninsular Malaysia is approximately 12,500 tonne/day. In year 2000, from another research done by JICA shows that solid waste which is managed by the local authority in Peninsular Malaysia is about 532,000 tonne (665000 m^3) every month (Jaringan Kerajaan Tempatan, 1999). From Housing Ministry and Local Government statistic (Azrina Sobian, 2003), in 2001, 16,247 tonne wastes are produced daily. If all solid waste is collected, and dumped at Dataran Merdeka Kuala Lumpur field for 6 months directly, it will create a mountain of solid waste that reach up to 421 metres which is equivalent to the height of Menara Kuala Lumpur (KL tower) the 4th highest telecommunication tower in the world.

In Peninsular Malaysia, the urban population has increased from 6.05 million (1988) to 8.7 million (1995) which is about 48% of the total population as compared to 100% urbanities in Singapore, and 94% urban population in Hong Kong (Agamuthu, 1997). During this period, the urban refuse collection service has been increased to cover 100% of the area, as shown in figure 1.1.

	1988	1995
Urban population in Peninsular Malaysia (thousands)	6050	8700
Refuse collection service coverage (%)	85	100
Served population (thousands)	5140	8700
Refuse generation rate (kg/capita/year)	240	277
Refuse bulk density (kg/m^3)	200	186
Collected refuse tonnage (thousand tonnes/year)	1260	2448
Collected refuse volume (thousand m^3/year)	6200	11600
Public cleansing service cost (million RM/year) (Street cleaning and waste management)	124	216

Note: Refuse collection service coverage in 1988 is based on the questionnaire on solid waste management. May 1987 (Agamuthu, 1997).

Figure 1.1. Estimated refuse amount and public cleansing service cost

STATE	SOLID WASTE (tonne/day)	
	1998	2000
Kuala Lumpur	2350	2800
Penang including S. Prai	1220	1400
Johore Bahru	450	500

Figure 1.2. Solid waste generated in major urban areas (Research source by JICA-1998)

The refuse generation rate has increased from 241 to 277 kg/capita/yr, at annual increment of 2%. The generation rate of solid waste was found to vary according to the type of waste generator and land use, as well as, economic level.

The cost of operation for solid waste management has escalated to RM60 per tonne, and RM216 million was spent on cleaning services in 1995 in which, about 67% was used for refuse management. In 1998, the cost of solid waste management increased to more than RM100 per tonne; whereas in 1988 the cost of operation was only RM30 per tonne. The actual cost may be much higher due to the ever-increasing wages, demand for better services and the sophistication of technical systems employed and the need for upgrading of the waste treatment systems. Urban migrant (from rural areas to urban areas) is the one of the immediate causes of high-density populations in some cities including Kuala Lumpur, the capital of Malaysia. This rapid increase in population is the one of the causes for an increase in refuse generation.

URBAN CENTRE	SOLID WASTE GENERATED (tonnes/day)		
	1970	1980	1990
Kuala Lumpur	98.8	310.5	586.8
Johor Bahru	41.1	99.6	174.8
Ipoh	22.5	82.7	162.2
Georgetown	53.4	83.0	137.2
Klang	18.0	65.0	122.8
Kuala Terengganu	8.7	61.8	121.0
Kota Bahru	9.1	56.5	102.9
Kuantan	7.1	45.2	85.3
Seremban	13.4	45.1	85.2
Malacca	14.4	29.1	46.8

Source: ICM/ICE, 1994

Figure 1.3. Solid waste generated in major urban areas in Peninsular Malaysia

STATE	ESTIMATED POPULATION	WASTE GENERATED (tonnes/day)	AMOUNT COLLECTED (tonnes/day)
Selangor	1583572	2375	1900
Kuala Lumpur	1446803	2257	2023
Sabah	2115546	1481	1037
Sarawak	2007528	1405	984
Perak	1618483	1295	906
Johor	1612650	1290	903
Kedah	1581483	1265	885
Penang	1290924	1033	723
Kelantan	1041311	833	583
Pahang	624660	508	358
Malacca	611481	489	342
Terengganu	583907	467	327
N. Sembilan	578035	462	323
Perlis	77650	62	43
Labuan	66146	46	32
TOTAL	16850179	15268	11369

Source: Ministry of Housing and Local Government, 1999.

Figure 1.5. Estimated solid waste generation in Malaysia in 1998.

YEAR	PROJECTED POPULATION	TOTAL WASTE GENERATION (tonnes/day)	PER CAPITA (kg/p/cp)
2000	607200	777.2	1.28
2005	695000	959.1	1.38
2010	777700	1158.8	1.49

Source: Master plan on Solid Waste Management for PJ Municipality (1990-2010)

Figure 1.4. Projected waste generation for Petaling Jaya.

YEAR	PROJECTED POPULATION	TOTAL WASTE GENERATION (tonnes/day)
2000	1787000	3070
2005	2150000	3478

Source: KL City Hall

Figure 1.6. Projected waste generation for Kuala Lumpur

YEAR	PROJECTED POPULATION	TOTAL WASTE GENERATION (tonnes/day)
2000	676000	680
2005	718000	784

Source: JICA (1989)

Figure 1.7. Projected waste generation for Penang (not including Seberang Prai)

Waste generation within Malaysia was found to depend very much on the sources of MSW. The rate of the waste generation varies greatly in terms of the premises (house, shop, etc.), affluence of population (low income or high income), occupation or business. Housing area is found to be the largest generator of waste in the country.

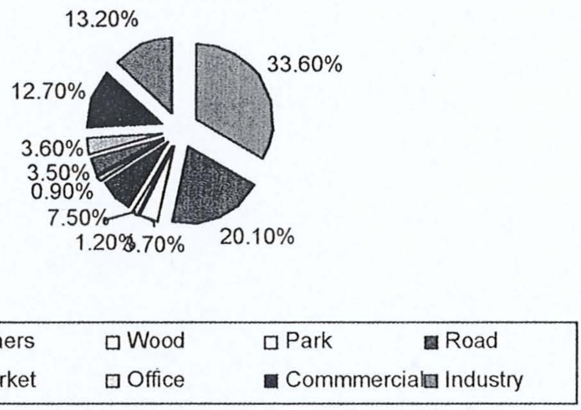


Figure 1.8. Waste generation in Malaysia

Operation and maintenance costs for managing solid waste are expensive. Research done by JICA (1988) mentions that 30% to 70% of local authority yearly income was used to manage the solid waste. There were cases where the costs of operation and maintenance are over than the local authority income and State Government were forced to give help. Currently, local authority is using the landfill system to dispose the solid waste. There were 177 landfills in Peninsular Malaysia and only 11 (6%) landfills were sanitary and 94 % were not sanitary. 78% of landfills were expected to close in year 2000. In Rancangan Malaysia ke-6, Federal Government spending about RM20.9 million to build 9 new sanitary landfills and upgrade 27 old landfills for 34 chosen local authority (Jaringan Kerajaan Tempatan. 1999). Total numbers of landfill in Peninsular Malaysia was divided into each states and types of landfills as shown in figure 1.9 :-

STATES	TYPES OF LANDFILL			TOTAL
	Open Dumping (Level 0)	Control Tipping (Level 1)	Sanitary Landfill (Level 2/3/4)*	
Perlis	0	1	0	1
Kedah	7	5	1	13
Penang	0	2	1	3
Selangor	7	9	2	18
Negeri Sembilan	7	6	0	13
Malacca	2	2	1	5
Johor	15	15	0	30
Pahang	22	8	2	32
Terengganu	9	8	1	18
Kelantan	14	3	0	17
Kuala Lumpur	0	0	1	1
Perak	7	17	2	26
TOTAL SUMS	90	76	11	177

Note: Sanitary landfills are divided into different levels. It can be upgraded into 4 different levels as listed below :
Level 0 - Open Dumping
Level 1 - Controlled Tipping
Level 2 - Sanitary landfills with bund and waste are buried everyday with cover soil.
Level 3 - Sanitary landfills with facility of leachate and air flow-piping system.
Level 4 - Sanitary landfills with facilities of treatment of leachate.

Figure 1.9. Numbers and types of landfills in Peninsular Malaysia (for the year 1998)

Dr. N Z Mahmood (2000) said that 90% of Malaysia's solid waste ends up in landfill with its attendant impact on air, water and land. Malaysia's strategy appeared to be diverting waste treatment away from landfills and to establish pilot areas to minimise and recycle solid wastes. Two key points to emerge from the presentation were the lack of policy and legislative frameworks that might be helpful in guiding solid waste management, and lack of political will and national strategies to facilitate and guide implementation. Malaysians generate about 72% compostable waste, comprising organic waste, paper, textile/leather and wood. The amount of plastic waste, which accounts for 16% is considered very high and is typical of a fast developing nation.

WASTE COMPOSITION	MSW CHARACTERISTICS (% by weight)
Organic/food waste	32.0
Paper	29.5
Textile/leather	3.4
Wood	7.0
Plastics	16.0
Rubber	2.0
Glass	4.5
Ceramics	0.4
Ferrous metal	3.7
Non-ferrous metal	0.6
Others	0.9

Figure 1.10. Malaysia waste composition (Agamuthu, 1997)

WASTE COMPOSITION	PJ	KL	SHAH ALAM	PENANG
Garbage	36.5	45.7	47.8	40.0
Plastics	16.4	9.0	14.0	15.0
Bottle/glass	3.1	3.9	4.3	4.0
Paper/cardboard	27.0	29.9	20.6	18.0
Metals	3.9	5.1	6.9	4.0
Fabric	3.1	2.1	2.4	6.0
Miscellaneous	10.0	4.3	4.0	9.0

Source: Malaysia industry, 1997
Figure 1.11. Solid waste composition (% by weight) of selected urban in Malaysia.

COMPONENT	kCAL/KG
Paper	2700-4500
Plastics	6500-9000
Rags	3600-4500
Rubber	5000-6500
Leather	3500-5000
Garden waste	500-4500
Wood	4000-4600

Figure 1.12. CV of some common constituents of MSW.

The net CV however depends on the degree of recycling, the degree of recycling of all the major components in the waste.

2. Small Scale Domestic Solid Waste Gasifier-combustor

2.1 Description

A small-scale gasifier-combustor has been developed in USM to address the increasing waste generated in the household. The domestic waste after separation process is fed into the primary chamber where the waste is ignited by a start up fuel. The capacity of the primary chamber (gasifier) is $0.064m^3$ able to contain 100 kg of equivalent wood chips. Air is supplied to gasify the waste. Temperature inside the primary chamber ranges from 800-1000°C. The gasified product, the producer gas is passed to a secondary chamber (combustor) where the gas is completely burnt with excess air. The secondary chamber has a capacity of $0.036m^3$. The temperature inside the secondary chamber is controlled at about 1000°C and the heat generated is transferred to water circulation system to produce steam or hot water. The combustion product in the secondary chamber enters a wet scrubber where it is cleaned and removed off any particulate present. The waste is completely burnt into ash collected at the bottom of the gasifier. The wet scrubber uses water from a sump and circulated through the scrubber.

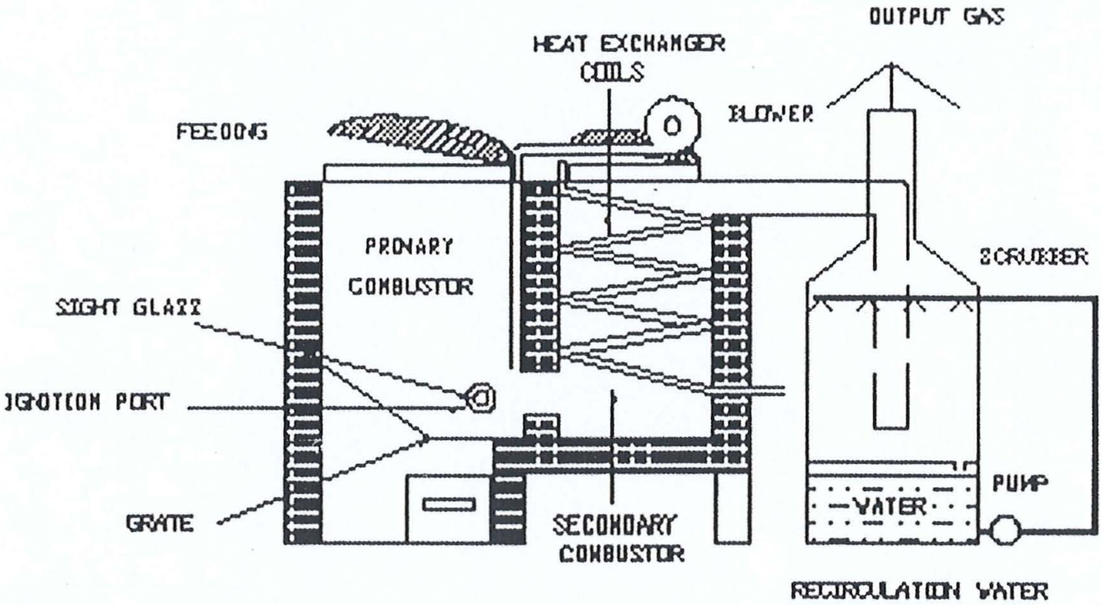


Figure 2.1. Main Components of Solid Waste and Biomass Gasifier-Combustor

2.2 Design

The system of the gasifier-combustor can be divided into 4 important stages:

2.2.1 Gasifier chamber

1. Feeding

A batch feeding system and can be converted into a continuous feeding system with a hopper and screw feeder, which means the wastes are fed-up continually into the chamber without stopping the combustion process. The feeding rate is 8 kg/hr to 10 kg/hr.

2. Sight glass

It is for viewing the ignition of flame to the waste and for viewing the condition of gasification process in the primary chamber specifically during the air flow rate setting. It uses a thick glass that can stand up the temperature of 1000^{0}C. The thickness of the glass is 10mm.

3. Ignition port

The waste is ignited by a start up fuel through this port. The start up fuel for the combustor is LPG gas.

4. Grate

The grate moves the wastes through the drying, burning and burnouts zone without promoting combustion. This is done to ensure that adequate quantities of air enter into the grate.

5. Ash bin

During the gasification process in the gasifier chamber, the ash will drop down through the grate into the ashbin. The location of the ashbin is exactly under the grate.

6. Primary air supply

A blower supplies the primary air, which has a specification shown in figure 5.2 below. It is located on the top of the combustor between the gasifier chamber and combustor chamber. The piping for the air inlet is located exactly beside the chamber cover and the length is 500 mm that is enough for supplying air to the chamber.

SIZE	63.5 mm	1/8 HP	50 Hz
VOL	0.5 – 4 m^3/min	0.5 Amp	3000 rpm
ST.Ps	8 – 50 mm. w. g	240 V	2 pole

Figure 2.2.1. Vnez electric blower, model SB-25.

7. Thermocouple holes

There are 4 holes for the thermocouple to measure the temperature distribution inside the gasifier chamber. The first 3 holes are for measuring the temperature inside the chamber and 1 hole for the flaming pyrolyzer zone.

2.2.2 Combustor chamber

1. Secondary air supply

A second blower supplies the secondary air, which has a specification shown in figure below. The location for the blower is next to the combustor chamber and the piping for air inlet is weld under the combustor chamber for supplying the air into the chamber to make sure the complete combustion can occurs.

Eph. TYPE	50 ps	CURRENT	2.9 A
NO./IP	8116/44	SPEED	2800 rpm
POWER	0.51 kW	VOL	1.7 – 10 m^3/min

Figure 2.2.2. Tian Yang, Radical Ventilator Super Power.

2. Thermocouple holes

There are 4 holes for the thermocouple to measuring the temperature distribution inside the combustor chamber. The first 3 holes are located inside the chamber and 1 hole is located at the flue gas exit.

2.2.3 Wet scrubber

Wet scrubber is used, into which the water is injected as the primary reagent for absorption of acid gases. The mode of injection is via nozzles. Wet scrubber can discharge a wet, salty effluent, which contains the acids, organics, metals and others pollutant impacted by the water droplets in the scrubber.

The water pump is used to pump the water from the tank (in the scrubber) to the nozzles. The specification for water pump is:

MODEL	KA 0525	OUTPUT	½ hp 0.37 kW
PIPE SIZE	25 m/m	FREQUENCY	50 Hz
HEAD	20 m	VOLT	230 V
QUANTITY	20 lpm	CURRENT	2.6 A
MAX. QUANTITY	48 lpm	RATING	CONT.
DATE	1997		

Figure 2.2.3. Kikawa pump.

2.2.4 Heat exchanger

It is used to reduce the temperature of gases, metals and organics, aiding in condensation. There are 2 types of heat exchanger, which are direct and indirect heat exchangers. Direct heat exchangers reduce the temperature of the gases via fine water droplets. Indirect heat exchangers reduce flue gas temperature by means of an intermediate substance that absorbs heat from the gas stream. Such absorbed heat is sometimes imparted back to the flue gases as they leave the system to increase buoyancy in the stack, reducing ambient impacts. The by-product of the system such as hot air, hot water or steam is produced throughout the heat exchanger coil inside the combustor chamber. With the operating temperature of 1000°C inside the combustor chamber, it is expected to produce hot air at the temperature of 200°C to 300°C and hot water at the temperature of 80°C to 100°C.

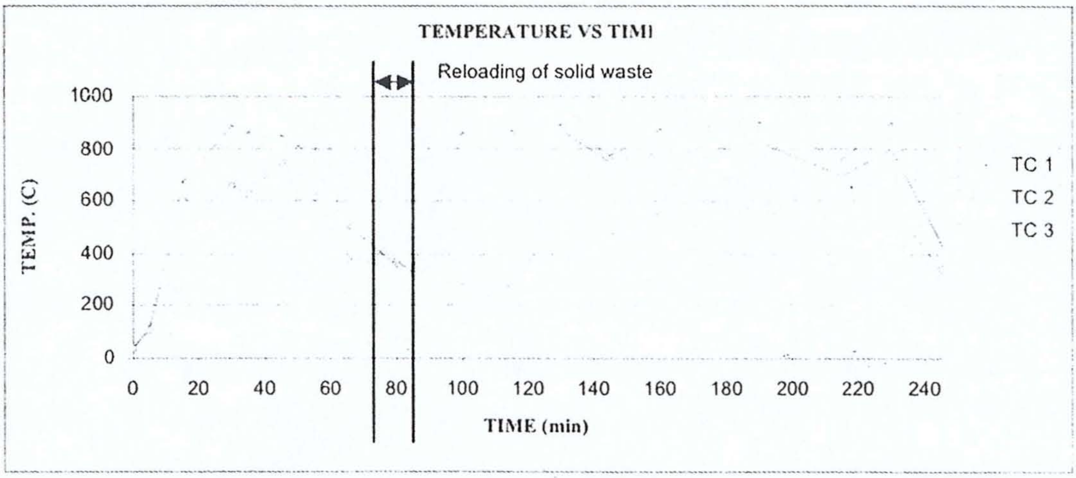
3. Experimental Work

Experimental work is done to investigate the combustion phenomena inside the gasifier and combustor chambers. The keys operating conditions to be considered pertaining to the minimization of air borne particulates/gases emission as well as the reduction of the volume of waste are as follow:

- Feedstock and feed control: attention to preparation of feedstock so as to avoid upset conditions within the combustor.
- Maximisation of combustion efficiency: adequate levels of temperature, stack effect, residence time, supply of air (oxygen) and turbulence within the combustor so as to ensure efficient burnout of the waste and minimization of the formation of dioxin.
- Management of the waste: attention to cooling for combustion gases and minimization of fly-ash build-up.
- Management of air pollution control device: management of temperature regime and installation of appropriate pollutants removal processes.
- Control and monitoring of system variables: control and monitoring of critical parameters such as excess oxygen, CO levels, temperature, etc.
- Emergency and fail-safe systems: the provision of design management measures that ensure the fail-safe response of the facility in the event of mal-operation or an-emergency.

3.1 Results & Discussion

The prime output of the experiment is the temperature profile of secondary (combustor) chamber in order to determine the capability of the system in achieving complete combustion process at the desired range of temperature. The experiment is conducted using wood chips (size : 50mm x 50mm x 100mm) as a source of fuel. The temperature profile is plotted as follow :-



**** Notes :** TC1 & TC2 (Thermocouples positioned inside the secondary chamber)
TC3 (Thermocouple positioned at the exhaust of the secondary chamber)

Figure 3.1 : Graph of Combustion Temperature (°C) VS. Time (min)

Process Data :

1st batch of waste feeding	: 20 kg
2nd batch of waste feeding	: 20 kg
Total of waste fed into gasifier chamber	: 40 kg
Total combustion time	: 4 hrs
Combustion rate	: 10 kg/hr

From Figure 3.1, it exemplifies that along the experiment, the temperature readings inside the combustor chamber (TC1 & TC2) are mostly reaching the expected level of 800°C – 1000°C. And the visual monitoring indicates no visible smoke emission with the verification of CO level below 100 ppm for most of the test run using gas analyzer. Hence, the result shows that a complete combustion process is achievable under the condition of sufficient air supply coming from the primary air blower, the secondary air blower and the surrounding air flowing into the combustor from top of the secondary chamber.

3.2 Conclusion and Recommendation

The solid waste gasification-combustion method is not used in Malaysia as much as overseas. This is partly historical because of the large expanses of land (apparently) available for landfill and cost of building the large scale gasifier-combustor.

However with increasing pressure on land and the potential for energy recovery, it could be a developing technology in Malaysia. Since that our population today keep increasing, the application of combustor would be applicable.

The smale scale solid waste gasifier-combustor has proven the capability of producing a clean flue gas under the process condition of complete combustion at the secondary chamber, the stake effect throughout the gasification-combustion process, proper management of combustion temperature to reach the expected level of 800°C to 1000°C with the excess air supply form the primary and the secondary air blowers as well as from the surrounding air through the ashbin container and the top cover of the secondary chamber. The CO level is below than 100 ppm that leads to a smoke less flue gas flowing out to the environment. Hence, the key operating conditions of the system have been met and the main objective of the system is achieved.

3.3 Improvement Actions

Based on few series of the experiment, there are few items of the gasification-combustion system that can be further improved :

- Thermocouples : Adding more locations for temperature measurement at both primary and secondary chambers for better reading of temperature distribution throughout the process. And the specification of the thermocouple rod to be changed from 3mm diameter x 200mm length to 5mm or 7mm diameter x 300mm – 400mm length for better accuracy of the measurement.
- Extension of combustion chamber to the top with chimney : This is to have more air from the surrounding coming into the combustor chamber to achieve a complete combustion process and to let the flue gas easily flowing out to the environment without any pressure drop in the combustor chamber.
- Preheat combustion : To have a preheat combustion process using the heat of the exhaust gas (range from 300°C to 500°C) to be supplied back into both gasifier and combustor chambers in order to increase as well as to maintain the temperature distribution at the gasifier chamber within a range of 800°C to 1000°C and the combustor chamber within a range of 900°C to 1000°C throughout the process. The application of the preheat combustion process will increase the system efficiency.

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5. Biography

Mohamad Yusof Idroas is an assistant lecturer in School of Mechanical Engineering, University Science of Malaysia. He is also a researcher under the field of Biomass Energy and becoming a member of Energy Research Unit of the university. Graduated from University of Arizona, Tucson, United States with Bachelor of Science in Mechanical Engineering in year 1994. Experienced working as a process engineer in a semiconductor company in Ipoh until year 2000 and later, decided to become a full time academician at University Science of Malaysia from year 2000 until now. Currently, he is pursuing his Master and Phd studies at Universiti Teknologi Malaysia, Skudai under the field of Biomass Energy Research.

His major work in research is focussing towards gasification and combustion process. Several papers and posters had been published and exhibited in few events such as in Industrial, Design & Technology (ITEX) 2004 KL under the project title "Domestic Solid Waste Gasifier-Combustor", IPTA 2003 Exhibition at PWTC KL under the project title "The Development of Low Cost Solid Waste Incinerator for Domestic & Industrial Use". Also involved in few collaborations in relation to gasification and combustion technology such as "The Development of Cyclone Gasifier System for Sawdust" , " Hydrogen Gas Filtration / Production from Flue Gas of Combustion Process " and " 10MW Biomass Fired Power Plant ".

Enabling MCSv5 for UDL Network.

By

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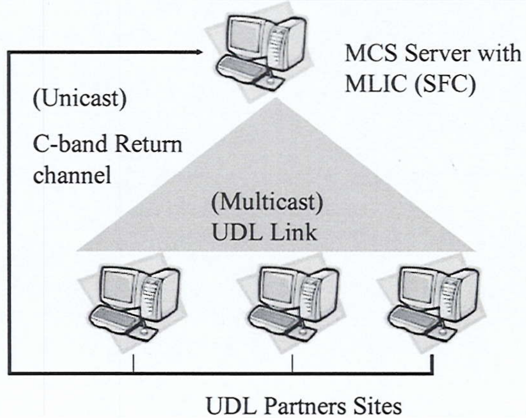
15 April 2004

Topology

- MCS server will be install near Hub site.
- Partners site will join VC through UDL network.
- Client will send video stream using unicast traffic thru C-Band Uplink and receive video stream from multicast traffic thru UDL downlink.
- MCS server with the MLIC component will convert unicast streams received to multicast stream and send to all other clients.

Topology

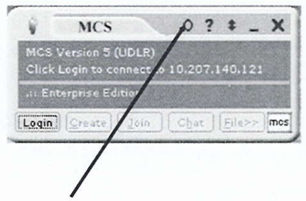


How to modify MCSv5 client for UDL

- Download the client software from http://www.usm.ai3.net/mcs.html
- Add this key in your registry file
  - HKEY_CURRENT_USER/software/Mlabs/Connection/UDLR (DWORD) 0x00000001
  - Or you can double click the registry key found on the website.

How to (cont')

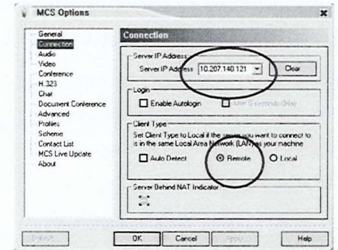
- Select the option page.



Option button

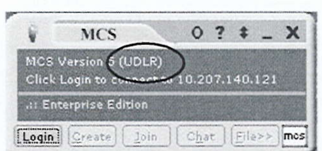
How to (cont')

- At Option page, select *connection*
- Put the relevant server IP of MCS server.
- Choose remote for client type



How to (cont')

- Restart the MCS client.
- Your client is now UDLR compatible if you see (UDLR) in the client type.



How to (cont')

- To change the MCS client back to normal, modify the registry key UDLR as mention in the earlier slide to 0x00000000.
- After restart the client. You should not see the (UDLR) sign in the client type.

Osprey video capture card issue

- Fix for Osprey card has been developed.
- Please visit the below site to modify the capture card default setting.
  - http://www.usm.ai3.net/mcs.html

How to for MCS Server

- MCS server involved license issue.
- Mlabs provide free license for SFC, NAIST and ASTI..?.
- MCS server installation will be done by Mlabs staff remotely.
- Please provide a RedHat 8.0 server with 256Mbps RAM and processor of at least Pentium 2.4G.
- Provide also a temporary *su* login.

Testing Plan

- SOI group agreed to collaborate in conducting a test on UDL network.
- First test will involved 2 sites namely from USM and SFC and ASTI.
- Second test will involved more sites, hopefully existing SOI partners.
- After the performance study and evaluation, we plan to come out with the stable version of MCS over UDL for SOI project.

Proposed Schedule

Date	Milestone
15 May 04	Installation of MCS server in SFC.
15 Jun 04	First test run of MCS on UDL network.
30 Jun 04	Second test run of MCS on UDL
15 July 04	Performance study and evaluation.

Questions?

- ML: multimedia@ai3.net

The End.
Thank You.