COMPARISON OF PROCESS FLOWS: FLUID BED COMBUSTOR AND GLASSPACK®

PURPOSE

The purpose of this document is to present the assumptions and calculations used to prepare Minergy Drawing 100-0204-PP00 (attached). The volumetric flows for both a fluid bed combustor (FBC) and Minergy's patented GlassPack® closed loop oxygen enhanced combustion process are compared on this drawing. In this drawing, process flows are illustrated by scaling the width of the flow arrows in direct proportion to the volumetric flow rates associated with each process as calculated below.

GENERAL ASSUMPTIONS

A sludge processing rate of 100 US dry tons per day of sludge (90.9 metric tons per day) was selected as a representative processing rate for this analysis for both technology options. Both options assume the same dry basis chemical analysis of the sludge. Feed stock was assumed to be undigested sludge with a carbon content of 40%, hydrogen content of 5%, nitrogen content of 5%, and oxygen content of 25% with a balance of ash at 25%. This analysis is typical of many undigested sludges currently found in the United States at this time.

FLUID BED COMBUSTOR PROCESS

The percent total solids content of the sludge fed to the FBC is assumed to be 25%, typical for many belt filter presses or centrifuge type dewatered sludges in the United States. The average dry basis feed to the FBC is therefore 3,788 kg/hr (90.9 dry metric tons per day).

Table 1 presents the theoretical air flow requirements for complete combustion of sludge and natural gas in the FBC. An auxiliary fuel requirement of 200 kg/hr of natural gas, to maintain good combustion and proper operating temperatures in the FBC, is included. Auxiliary fuel requirements very from design to design and are impacted by a wide number of variables. The

Table 1: Total Air Requirement for Fluid Bed Combustor

	Mass (%)	Total Dry Basis Feed Rate (kg/hr)	Theoretical Air Required (kg/kg)	Theoretical Air Required (kg/hr)
Sludge Composition				
Carbon	40%	1515	11.49	17,410
Hydrogen	5%	189	34.48	6,531
Nitrogen	5%	189	0	-
Oxygen	25%	947	-4.3	(4,072)
Ash	25%	947	0	-
Total (sludge)	100%	3788		**19,868**
Co-fire Fuel Composition				
Natural Gas (Methane)	100%	200	17.24	**3,448**
Total air required (sludge + natural gas)				**23,316**
Excess air (50%)				11,658
Total Air				**34,974**

auxiliary fuel needs are based on industry averages of US design FBCs processing wastewater treatment sludges. An excess air flow requirement of 50% for the FBC was also incorporated and is based on data from FBCs currently operating in the US.

Table 2 presents a simple mass balance around the FBC and accounts for the major inputs. Other sub-processes such as sand degradation, limestone addition, and ammonia injection have been excluded from this analysis due to the very small mass flows associated with each of these flow streams.

Table 2. Combustor Mass Balance for Fluid Bed Combustor

Stream	kg/hr	Basis
Combustion Air	34,974	Table 1
Organic Fraction of Sludge	2,841	3788kg/hr at 75% organic content
Water Evaporated From Sludge	11,364	3788 kg/hr dry solids content at 25% dry solids content
Natural Gas	200	Table 1
Total Exhaust Gas Mass Flow:	**49,379**	

Table 3 presents the conversion from mass flow to volumetric flow using the Ideal Gas Laws. The exhaust gas temperatures from the FBC are assumed to be 182° C (455° K). The molecular weight of the flue gas is less than most flue gases due to the high water vapor content. Calculations presented in Table 3 result in volumes of combustion air required and exhaust gas flows from the FBC to be 28,205 m^3/hr and 72,621 m^3/hr, respectively.

Table 3. Conversion of Mass Flow Rate to Volume for Fluid Bed Combustor

Exhaust Gas		
Mass Flow Rate	49,379,090	grams/hr
Molecular Weight	25.40	
Pressure at Exhaust Stack	1.00	atm
Temperature of Exhaust	455	deg K
Gas Constant	0.0821	liter*atm/mole deg K
Exhaust Gas Volume	72,621,283	l/hr
Exhaust Gas Volume	72,621	m^3/hr
Combustion Air		
Mass Flow Rate	34,974,090	grams/hr
Molecular Weight	28.96	
Pressure at FD Fan Outlet	1.03	atm
Temperature of Combustion Air	293	deg K
Gas Constant	0.0821	liter*atm/mole deg K
Combustion Air Volume	28,204,696	l/hr
Combustion Air Volume	28,205	m^3/hr

MINERGY GLASSPACK® PROCESS

Minergy has assumed that the same volume of sludge fed to the fluid bed combustor case is first pre-dried in an indirect thermal dryer. The water vapor discharge from the dryer is condensed into the liquid state and is not discharged to the atmosphere. The sludge is dried down to 90% total solids content before it is processed in the GlassPack® melter process.

Table 4 presents the theoretical oxygen and air flow, respectively, for complete combustion of the sludge in a GlassPack® unit. No natural gas is required to support combustion in the GlassPack® process at steady state conditions. A 12% excess oxygen rate, a conservative assumption established through extensive testing at Minergy's GlassPack® pilot unit, has also been included.

Table 4: Total Air Requirement for GlassPack®

	Mass (%)	Total Dry Basis Feed Rate (kg/hr)	Theoretical Air Required (kg/kg)	Theoretical Air Required (kg/hr)
Sludge Composition				
Carbon	40%	1515	2.67	4,046
Hydrogen	5%	189	8	1,515
Nitrogen	5%	189	0	-
Oxygen	25%	947	-1	(947)
Ash	25%	947	0	-
Total (sludge)	100%	3788		**4,614**
Co-fire Fuel Composition				
Natural Gas (Methane)	100%	0	4	**-**
			Total air required (sludge + natural gas)	**4,614**
			Excess Oxygen (12%)	554
			Total Air	**5,167**

Table 5 is a simple mass balance around the GlassPack® combustion process. The mass balance includes a credit for condensation of water vapor in the scrubber condenser which is integral to the GlassPack® process.

Table 5. Combustor Mass Balance for GlassPack®

Stream	kg/hr	Basis
Oxygen for Combustion	5,167	Table 1
Organic Fraction of Sludge	2,841	3788kg/hr * 75% organic content
Water Evaporated from Sludge	421	3788 kg/hr dry solids content at 90% dry solids content
Natural Gas	-	Table 1
Water Vapor Condensed in Process	(825)	
Total Exhaust Gas Mass Flow:	**7,604**	

Table 6 presents the volumetric conversion assumptions used for the oxygen requirement and exhaust gas production volumes from the GlassPack® process. The volumes are 4,240 m^3/hr and 5,619 m^3/hr for oxygen supply and exhaust gas flows, respectively. The oxygen temperature is assumed to be 50°C with an exhaust gas temperature assumed to be 60°C.

Table 6. Conversion of Mass Flow Rate to Volume forGlassPack®

Exhaust Gas		
Mass Flow Rate	7,604,327	grams/hr
Molecular Weight	37.00	
Pressure at Exhaust Stack	1.00	atm
Temperature of Exhaust	333	deg K
Gas Constant	0.0821	liter*atm/mole deg K
Exhaust Gas Volume	5,618,837	l/hr
Exhaust Gas Volume	5,619	m^3/hr
Combustion Air		
Mass Flow Rate	5,167,438	grams/hr
Molecular Weight	32.00	
Pressure at FD Fan Outlet	1.01	atm
Temperature of Oxygen	323	deg K
Gas Constant	0.0821	liter*atm/mole deg K
Combustion Oxygen Volume	4,239,841	l/hr
Combustion Oxygen Volume	4,240	m^3/hr

CONCLUSIONS

The process flow volumes between the two technologies are remarkably different. The main contributing factors to the higher volumes in the fluid bed combustor are:

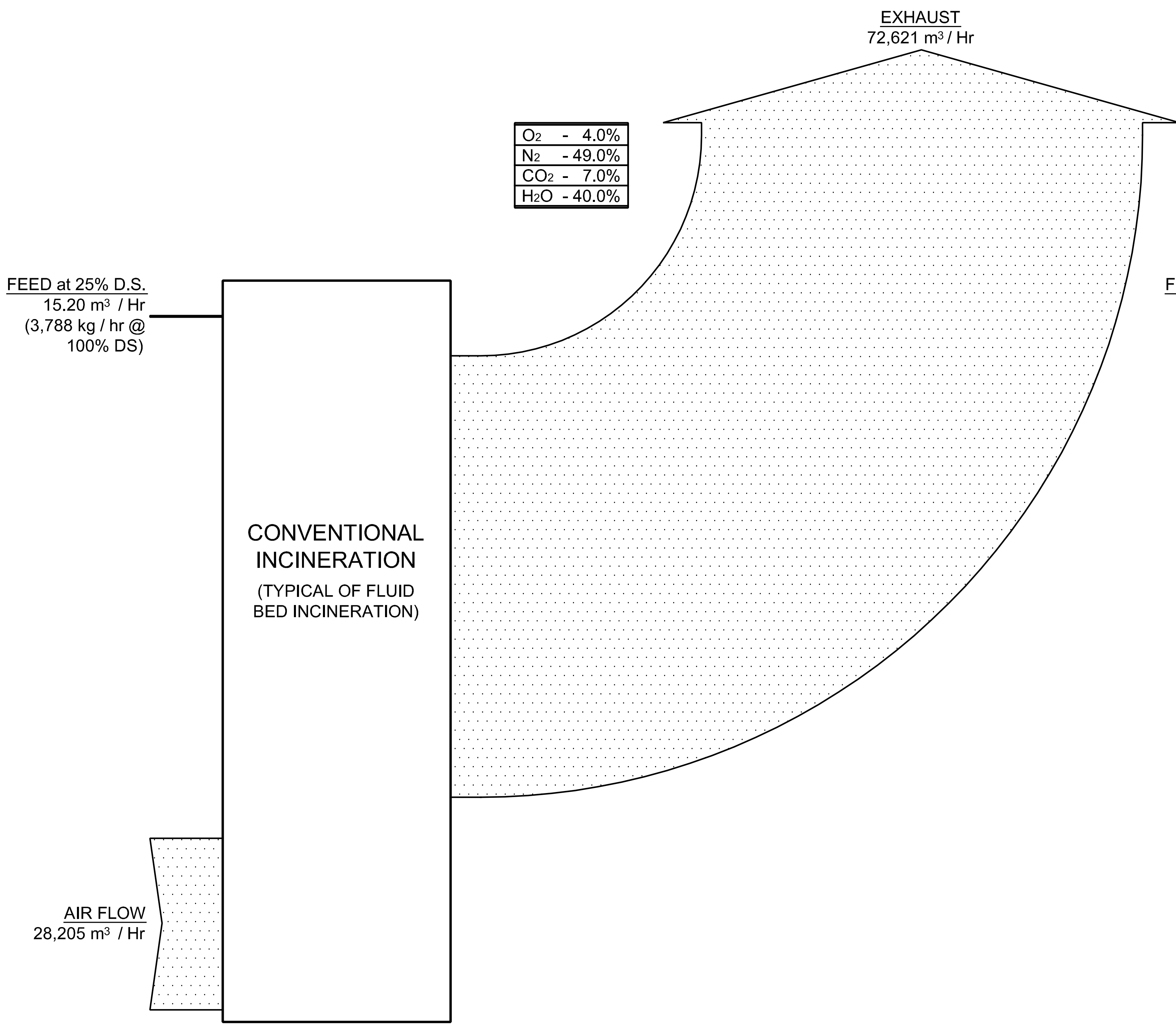
1. The fluid bed combustor is a large water evaporator, thus discharging all of the water vapor evaporated in the process into the ambient air.

2. The use of air fired combustion introduces a significant volume of nitrogen which has no particular benefit in the combustion process.

The process volumes impact combustor size, combustor capital cost, forced draft and induced draft fan size, fan drive power requirements, the size of the air quality control equipment and the capital cost of the air quality control equipment.

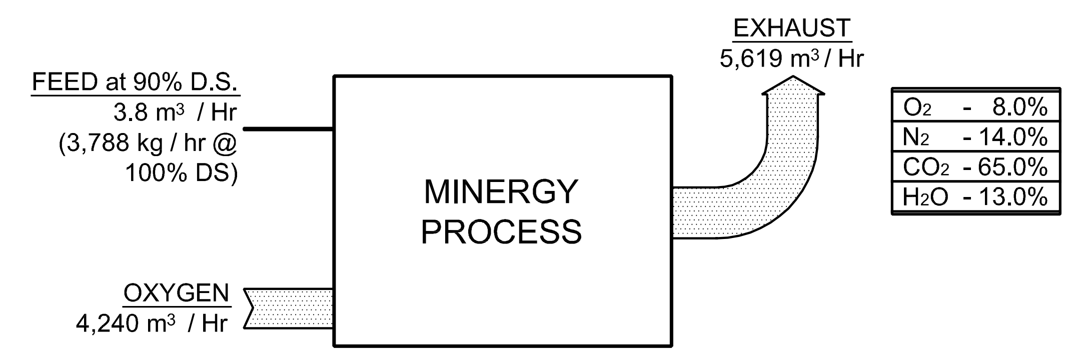
PROCESS VOLUMES

AIR FIRED INCINERATION



PROCESS VOLUMES

OXYGEN ENHANCED COMBUSTION & MELTER



Rev. No.	Revision Description	Date	Drwn.	Chk'd

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GLASSPACK, LLC
GP100 MELTER PLANT

PLANT PERFORMANCE
PROCESS VOLUMES
COMPARISON EVALUATIONS

Date: APRIL 2005

Drawing No.: 100-0200-PP00

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