Comparing Total Mine Airflow Requirements using a comprehensive new approach vs. traditional method(s)

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Overview

- In an effort to improve overall air quality, the U.S. EPA mandated compliance with the so called "Clean Air Rules of 2004", that were designed to decrease emissions from nonroad diesel engines by more than 90%, with the final Tier IV regulations becoming effective in 2014.
- Once implemented, the EPA Tier IV/Euro Phase IV regulations resulted in confusion and uncertainty regarding the amount of airflow required to safely operate diesel equipment in underground mines.
- Traditionally, total airflow requirements for underground mines were based upon the power of the underground diesel fleet.
- In 2013, a new method was devised to address this need within the industry for a specific, repeatable protocol for calculating total airflow quantities required for the ventilation of underground diesel equipment.

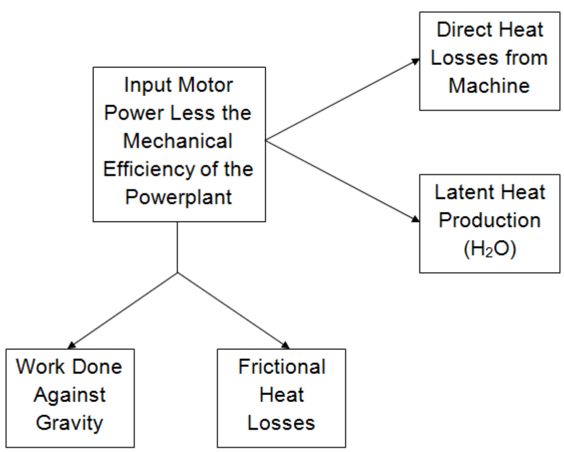
Diesel Contaminant Products

- toxic gases (CO, CO_2, NO_x)
- particulates (DPM)
- heat
- mineral dust

- Each component has unique qualities that pose particular threats to humans and require individual mitigation strategies.

Heat

Diesel-powered equipment can produce 2 – 3 times as much heat (kW) as mechanical work (kW).



Heat Production of Diesel Engines by Type/Mode.

Mineral Dust

- Classification

- component particle size (respirable and non-respirable)
- mineral composition (e.g. silica, asbestos, coal, etc.).

- Toxic Dust
- Carcinogenic Dust
- Fibrogenic Dust
- Explosive Dust
- Nuisance Dust

- The negative health effects of various forms of dust can vary significantly from minor discomfort to acute and life-threatening symptoms.

Existing Method(s)

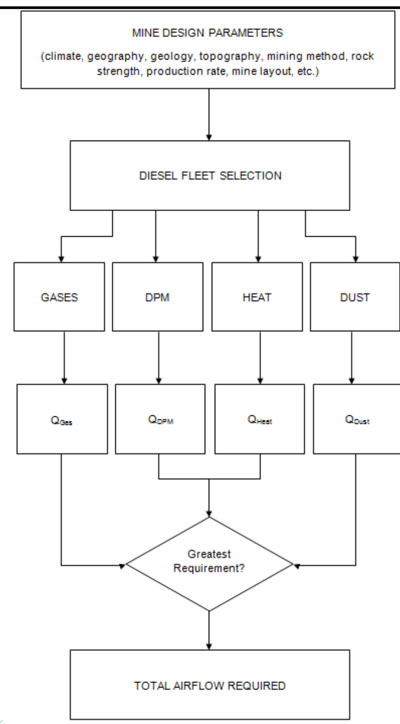
- Multiplier of the equipment power and with reductions made for the utilization and/or availability of individual pieces of equipment.
- Disadvantages
  - non-scientific / experience based
  - inefficient
  - unpredictable

- Nameplate or Approval rates for individual engines.
- Disadvantages
  - engine-specific information may not be available
  - does not account for heat and dust

Proposed New Method

- The proposed new method accounts for all four contaminant types generated by underground diesel equipment (i.e., Gases, Particulates, Heat and Dust).
- The proposed new method is based on existing scientific knowledge and principles.
- The new method has been demonstrated to be practicable and "reasonable".

Proposed New Method



Relationship between Design Parameters and Ventilation Rates.

Gaseous POC and DPM

Historic Ventilation Rates for Approved MSHA Engines (Haney, 2012).

EPA Tier	Number of Engines Tested	Gaseous Vent Rate, $m^3/s/kW$ (cfm/hp)	PI, $m^3/s/kW$ (cfm/hp)	5 × PI, $m^3/s/kW$ (cfm/hp)
Non EPA Compliant Less than 73 kW (99 hp)	21	0.050 ± 0.057 (79 ± 90)	0.119 ± 0.088 (188 ± 139)	0.595 ± 0.438 (942 ± 693)
Non EPA Compliant Gr. or Eq. to 73 kW (99 hp)	41	0.038 ± 0.0076 (60 ± 12)	0.059 ± 0.024 (94 ± 38)	0.297 ± 0.119 (468 ± 188)
Tier 1/2 Less than 73 kW (99 hp)	73	0.030 ± 0.0095 (60 ± 15)*	0.041 ± 0.015 (65 ± 24)	0.206 ± 0.076 (324 ± 120)
Tier 1/2 Gr. or Eq. to 73 kW (99 hp)	**141**	**0.035 ± 0.0076 (55 ± 12)***	**0.012 ± 0.0095 (31 ± 15)**	**0.098 ± 0.047 (156 ± 74)**
Tier 3 Less than 73 kW (99 hp)	27	0.032 ± 0.0044 (50 ± 7)**	0.028 ± 0.015 (44 ± 23)	0.139 ± 0.071 (219 ± 113)
Tier 3 Gr. or Eq. to 73 kW (99 hp)	**47**	**0.025 ± 0.0032 (39 ± 5)****	**0.025 ± 0.0089 (39 ± 14)**	**0.123 ± 0.046 (194 ± 72)**
Tier 4	**2**	**0.025 ± 0.0032 (39 ± 5)****	**0.002 (3.2)*****	**0.010 (16.0)*****

*Based on NO **Based on CO_2 ***Based of a PI of 0.01 gm/hp-hr.

Gaseous POC and DPM

- Approved ventilation rates should be available in the future for all Tier IV engines, and nameplate values from NRCan and MSHA can be used for existing equipment fleets and older engines provided that the airflow required based on the contaminants of heat and dust are also calculated.
- For more general calculations, a value of 0.025 m^3/s per kW (0.022 – 0.028) may be used for determining the airflow required for diluting gaseous contaminants and 0.010 m^3/s per kW (0.009 – 0.011) for DPM.

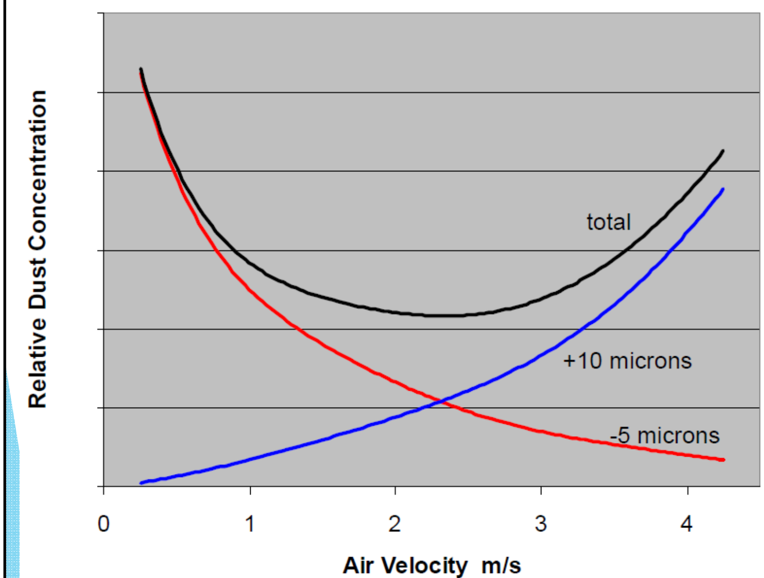
Heat

- Calculating the heat production from a diesel-powered machine can be practically accomplished through the following process(es):
- First, the **Total Heat** is determined based on the fuel consumption rate…
- Next, the **Latent Heat** is calculated…
- The **Sensible Heat** generated is simply the difference between the Total Heat and the Latent Heat…
- The associated **temperature** rise in the ambient air across the machine is a function of the mass flow rate of air (set to a certain point to ensure that conditions do not reach the design criteria for stop-work temperature)…
- The **mass flow rate** of air should be converted to a **volume flow rate** for comparison to the other ventilation rates.

Mineral Dust

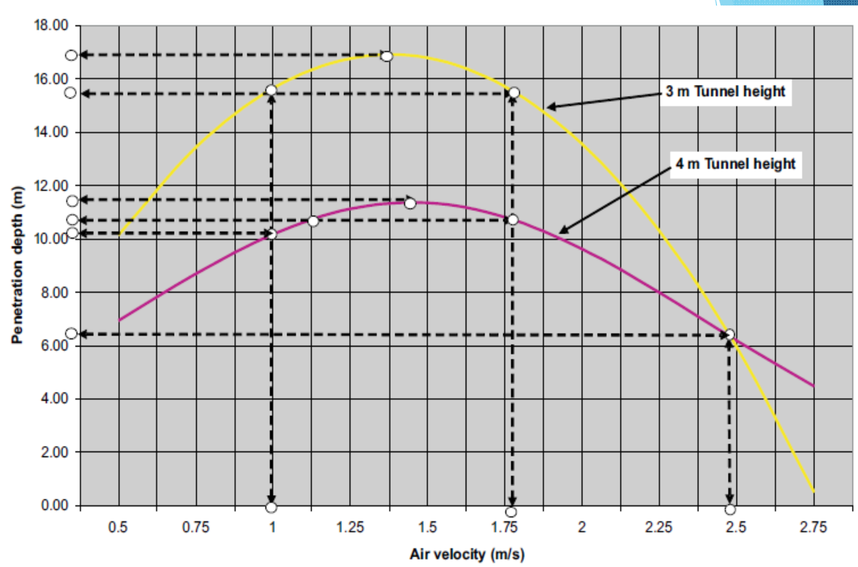
- Dust created by diesel-powered equipment does not vary significantly from that generated by older equipment; the examination of how much airflow is required to remove the hazard has become more important based on the reduction(s) of the airflow required based on other contaminant products (i.e. gases, DPM).
- Ventilation remains the most commonly used means of removing mineral dust from the underground environment.
- Respirable (sub-micron) dust settles from the airstream at an almost negligible rate, and should be controlled via dilution in a manner similar to other gaseous contaminants. In the case of larger particles it is primarily the airflow velocity that dictates the distance and time the dust particles will be entrained in the air stream.

Mineral Dust



Dust Concentrations at Various Air Velocities (McPherson, 2009).

Mineral Dust



Air Penetration Depth vs. Airflow Velocity (Rawlins and Phillips, 2005).

Comparison of Methods

- The total airflow required for an LHD was determined utilizing the existing methods of Direct Engine Testing and Empirical Derivation, as well as individually for the contaminants of Gaseous POC, DPM, Heat and Dust.
- The LHD selected for this comparison is the commercially available Sandvik LH517 powered by a Volvo TAD1361VE 285 kW Tier IVi engine.
- This LHD has a capacity of 17,200 kg or 7 cubic meters and is approved for use underground by NRCan under CSA M424.2-90 (non-gassy mines).
- Minimum drift dimensions of approximately 5 m wide by 6.5 m high are required for this Loader to achieve full mobility.

Comparison of Methods

Comparison of Methods for Calculating Required LHD Airflow.

Method of Determining Airflow	Total Airflow (m^3/s)	Ventilation Rate (m^3/s per kW)	% of Greatest (%)
Direct Engine Testing*	5.9	0.021	18%
Empirical Derivation	18.0	0.063	55%
Proposed Method Gaseous POC	8.0	0.028	25%
Proposed Method DPM	3.1	0.011	10%
Proposed Method Heat	21.4	0.075	66%
Proposed Method Dust	32.5	N/A	100%

*NRCan, 2011.

Comparison of Methods

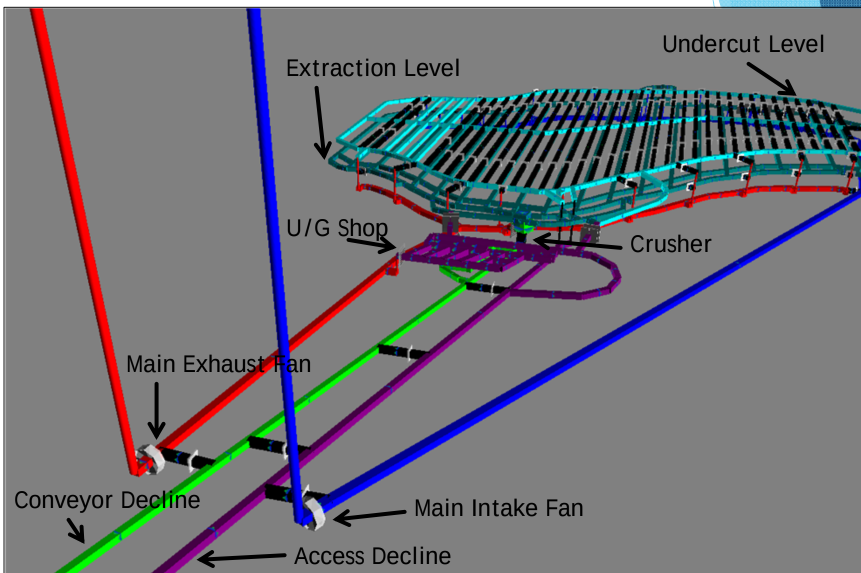
- Despite the significant reductions made in the gaseous POC and DPM emissions of the Tier IVi engine, the overall airflow required has not significantly changed, and may even be increased in cases where the critical design parameters of heat and dust were not previous considered.

- Clearly, a 90% reduction in required airflow that many anticipated based upon a similar decrease in the amount of gaseous and particulate contaminants at the tailpipe is not justified.

Case Study

- A case study was performed to comprehensively evaluate the differences between the proposed new model for determining total airflow requirement for the diesel fleet.
- The mine chosen for this study was a North American metal mine that utilizes the block-caving technique for mineral extraction.
- Airflow requirements were first calculated using established techniques (statutory compliance dictates ventilation rates of 0.063 m^3/s per kW of engine power).
- The total airflow was then determined based on the method(s) outlined in this thesis for the purpose of comparison.

Case Study



Isometric View of the Main Mining Area.

Case Study – Development Airflow

Equipment	Utilization (%)	Power (kW)	Quantity	Airflow (m^3/s)	Total (m^3/s)
LHD	100%	291	2	17.5	35
Haul Truck	95%	410	2	23.4	47
Light Duty Vehicle	100%	111	2	6.7	13
Jumbo/Bolter	50%	111	2	3.3	6.66
				Sum:	102

Equipment	Utilization (%)	Power (kW)	Quantity	Gas Q (m^3/s)	DPM Q (m^3/s)	Heat Q (m^3/s)	Dust Q* (m^3/s)	Total** (m^3/s)
LHD	100%	291	2	8.1	3.2	23.9	22.5	48
Haul Truck	100%	410	2	11.5	4.5	33.6	25.0	67
Light Duty Vehicle	100%	111	2	3.1	1.2	9.1	25.0	18
Jumbo/Bolter	100%	111	2	3.1	1.2	9.1	25.0	18
				Sum:				151

Case Study – Life of Mine Airflow

Equipment	Utilization (%)	Power (kW)	Quantity	Airflow (m^3/s)	Total (m^3/s)
LHD	100%	291	14	17.5	244
Haul Truck	95%	410	2	23.4	47
Light Duty Vehicle	65%	111	5	4.3	22
Jumbo	15%	111	6	1.0	6
Shotcrete Truck	75%	200	3	9.0	27
Road Grader	25%	265	1	4.0	15
Shop	100%	N/A	1	40.0	40
Conveyor	100%	N/A	1	25.0	25
				Sum:	426

Equipment	Utilization (%)	Power (kW)	Quantity	Gas Q (m^3/s)	DPM Q (m^3/s)	Heat Q (m^3/s)	Dust Q* (m^3/s)	Total** (m^3/s)
LHD	100%	291	14	8.1	3.2	23.9	22.5	335
Haul Truck	95%	410	2	10.9	4.3	33.6	25.0	64
Light Duty Vehicle	65%	111	5	2.0	0.8	9.1	25.0	30
Jumbo	15%	111	6	0.5	0.2	9.1	25.0	8
Shotcrete Truck	75%	200	3	4.2	1.7	16.4	25.0	37
Road Grader	25%	265	1	1.9	0.7	21.7	25.0	5
Shop	100%	N/A	1	40.0	40.0	40.0	40.0	40
Conveyor	100%	N/A	1	25.0	25.0	25.0	25.0	25
			Sum:					544

*Based on the cross-sectional area of the drift where the equipment will most often be used.

**Based on the airflow required to mitigate the heat of the equipment

Case Study – LOM Capital Costs

Fan Installations:	Quantity (m^3/s)	Pressure (kPa)	Air Power @ 75% Eff. (kW)	VFD Required? (Yes/No)	Heat Required? (Yes/No)	Heater Size (Max) (MW)
Intake Raise	200	3	800	Yes	Yes	10.0
Exhaust Raise	200	3	800	Yes	No	N/A
Decline	68	1.5	136	Yes	Yes	2.0

Fan Installations:	Quantity (No.)	Unit Cost ($US)	VFD Cost ($US)	Monitoring ($US)	Sub-Total ($US)	Total ($US)
Intake Raise	2	$ 520,600	$ 218,750	$ 25,600	$ 1,529,900	$ 1,529,900
Exhaust Raise	2	$ 520,600	$ 218,750	$ 25,600	$ 1,529,900	$ 3,059,800
Conveyor Decline	2	$ 68,000	$ 25,000	$ 25,600	$ 237,200	**$ 3,297,000**

Ventilation Raises	Quantity (No.)	Unit Cost ($US)	Method of Excavation	Length (m)	Sub-Total ($US)	Total ($US)
Intake Raise	1	$ 8,200	Raise-Bore	720	$ 5,904,000	$ 5,904,000
Haulage Decline	1	$ 8,200	Raise-Bore	720	$ 5,904,000	**$ 11,808,000**

Equipment Installations:	Quantity (No.)	Unit Cost ($US)	Sub-Total ($US)	Total ($US)
Airlock Doors/Fire Doors	34	$ 25,000	$ 850,000	$ 850,000
Panel Regulators	20	$ 2,500	$ 50,000	$ 900,000
Airflow Quantity Sensors	25	$ 3,000	$ 75,000	$ 975,000
Airflow Quality Sensors	34	$ 5,000	$ 170,000	$ 1,145,000
Mine Weather Stations	4	$ 2,000	$ 8,000	**$ 1,153,000**

Case Study – LOM Capital Costs

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Ventilation Raises	Quantity (No.)	Unit Cost ($US)	Method of Excavation	Length (m)	Sub-Total ($US)	Total ($US)
Intake Raise	1	$ 12,500	Raise-Bore	720	$ 9,000,000	$ 9,000,000
Haulage Decline	1	$ 12,500	Raise-Bore	720	$ 9,000,000	**$ 18,000,000**

Equipment Installations:	Quantity (No.)	Unit Cost ($US)	Sub-Total ($US)	Total ($US)
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Case Study – LOM Operating Costs

Fan Installations:	Quantity (m³/s)	Pressure (kPa)	Efficiency (%)	Power (kW)	Annual Cost ($US)	Total ($US)
Intake Raise	365	2.7	75%	1314	$ 460,426	$ 460,426
Exhaust Raise	400	2.6	75%	1387	$ 485,888	$ 946,314
Conveyor Decline	35	0.25	75%	12	$ 4,088	**$ 950,402**

Fan Installations:	Quantity (m³/s)	Pressure (kPa)	Efficiency (%)	Power (kW)	Annual Cost ($US)	Total ($US)
Intake Raise	445	2.5	75%	1494	$ 523,861	$ 523,861
Exhaust Raise	475	2.0	75%	1286	$ 450,806	$ 974,667
Conveyor Decline	40	0.25	75%	13	$ 4,675	**$ 979,342**

Case Study

- Other impacts included the slight increase in the size of the auxiliary duct diameter from 1.4-m to 1.5-m (resulting in decreased equipment clearance and a likely increase in both leakage (operating) and maintenance costs associated with the auxiliary ventilation systems.
- Although there was an increase in the amount of air required for the LHDs in the production panels this did not result in significantly higher airflows on the Extraction Level owing to the fact that these areas were previous limited by airflow velocity criteria (which at 1 m/s on the 5 m by 4.5 m drifts already required additional airflow over what was required for the equipment based solely on engine power).

Case Study

- It should be noted that the equipment chosen for this case study was already Tier IVi, and a ventilation multiplier (0.063 m^3/s per kW) was used to determine the original flows.
- The resulting change between scenarios is not as dramatic as it could have been (e.g. if nameplate ventilation rates for Tier III equipment had been compared).

Conclusions

- Given the significant reductions in the emissions of modern diesel equipment, total flow calculations will not be calculated based solely on tailpipe emissions.
- heat is now *likely* to be the determining factor in calculating airflow requirements for diesel engines except in cases of cold-climate mines and/or where other dust control methods (i.e., water) are not effectively utilized (or not possible).
- Based on heat production, a sensitivity analysis showed that the amount of air required varied from approximately 0.06 m^3/s per kW to 0.094 m^3/s per kW over the range of conditions likely to be encountered in most mining scenarios with a rate of 0.075 m^3/s per kW for "average".

Ventilation Rate for Heat

Assumptions:	
engine power:	300 kW
fuel consumption:	0.3 litres/kWhr
combustion efficiency:	95%
calorific value of diesel fuel:	34000 kJ/litre
water produced per litre of fuel:	5 litres
latent heat of the evaporation of water:	2450 kJ/kg
specific heat of dry air:	1.005 kJ/kgK
temperature rise across machine:	20 deg. C
air density:	1.2 kg/m^3
Calculations:	
fuel consumed:	90 litres/hr
Total Heat Produced:	850 kW
Latent Heat Produced:	306 kW
Sensible Heat Produced:	544 kW
Heat Produced per kilowatt of mechanical output:	2.83
Mass Flow Rate of Air Required:	27.1 kg/s
Volume Flow Rate of Air Required:	22.5 m^3/s
Ventilation Rate Required:	0.075 m^3/s per kW

Sensitivity – Fuel Consumption

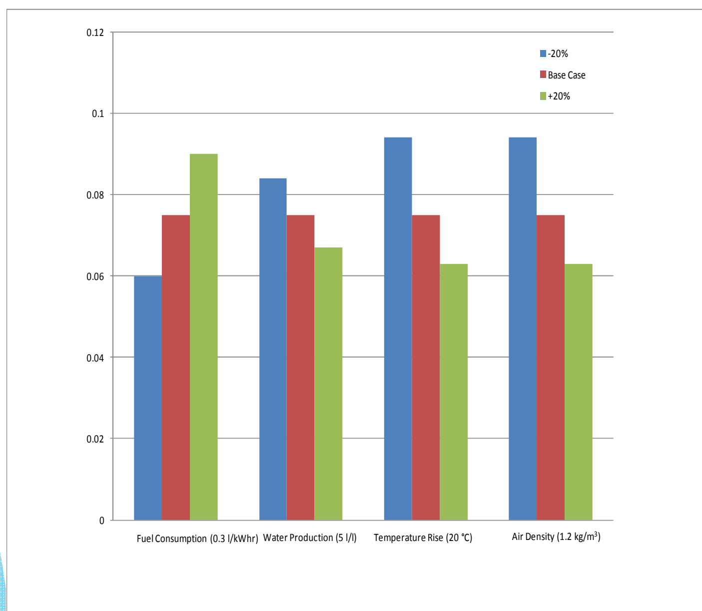
Assumptions:

engine power:	300 kW	engine power:	300 kW
fuel consumption:	**0.24 litres/kWhr**	**fuel consumption:**	**0.36 litres/kWhr**
combustion efficiency:	95%	combustion efficiency:	95%
calorific value of diesel fuel:	34000 kJ/litre	calorific value of diesel fuel:	34000 kJ/litre
water produced per litre of fuel:	5 litres	water produced per litre of fuel:	5 litres
latent heat of the evaporation of water:	2450 kJ/kg	latent heat of the evaporation of water:	2450 kJ/kg
specific heat of dry air:	1.005 kJ/kgK	specific heat of dry air:	1.005 kJ/kgK
temperature rise across machine:	20 deg. C	temperature rise across machine:	20 deg. C
air density:	1.2 kg/m^3	air density:	1.2 kg/m^3

Calculations:

fuel consumed:	72 litres/hr	fuel consumed:	108 litres/hr
Total Heat Produced:	680 kW	Total Heat Produced:	1020 kW
Latent Heat Produced:	245 kW	Latent Heat Produced:	368 kW
Sensible Heat Produced:	435 kW	Sensible Heat Produced:	653 kW
Heat Produced per kilowatt of mechanical output:	2.27	Heat Produced per kilowatt of mechanical output:	3.40
Mass Flow Rate of Air Required:	21.6 kg/s	Mass Flow Rate of Air Required:	32.5 kg/s
Volume Flow Rate of Air Required:	18.0 m^3/s	Volume Flow Rate of Air Required:	27.1 m^3/s
Ventilation Rate Required:	0.060 m^3/s per kW	Ventilation Rate Required:	0.090 m^3/s per kW

Sensitivity – All Parameters




Questions?