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CFD Modeling of Tractor Emissions in the Near-Field: Implications for Occupational Health and Agro-Environmental Quality

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INTRODUCTION & AIM

The Philippines remains a labor-intensive rice-producing country, with only land preparation, harvesting, and threshing partially mechanized using two-wheel tractors and axial threshers.

A walking type agricultural tractor is used for pulling or propelling agricultural implements, operates on fossil fuels, which contribute to air pollution and potential operator exposure to exhaust emissions.

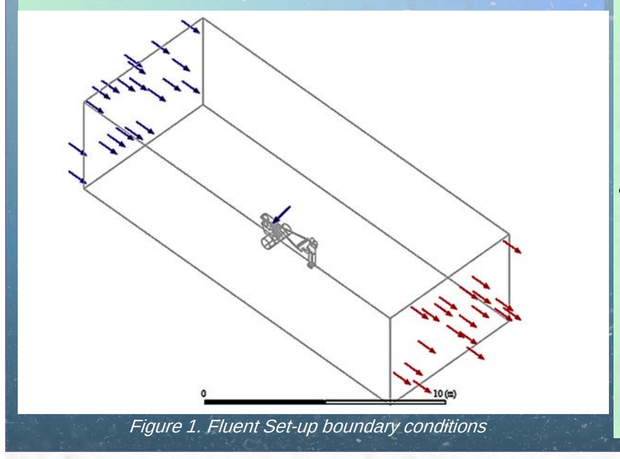
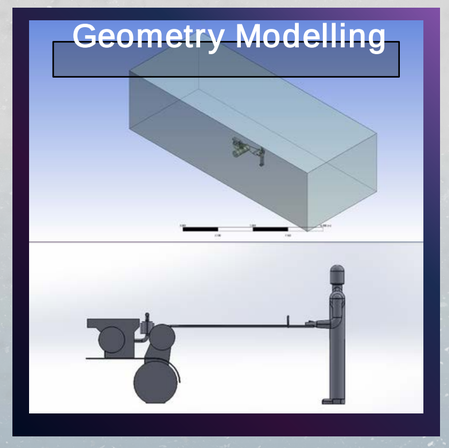
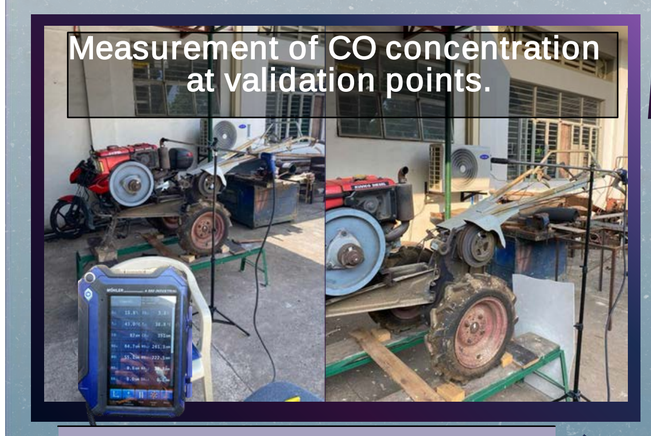


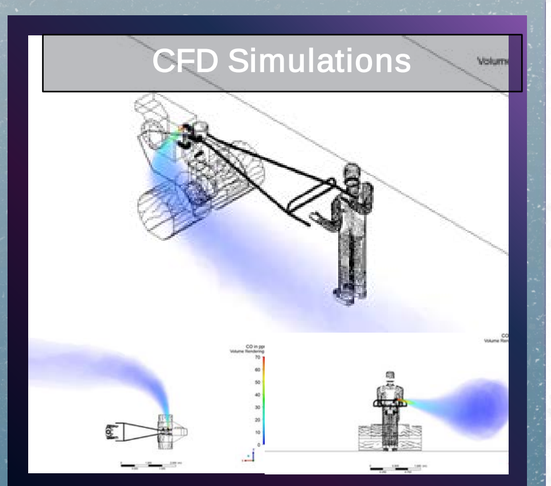
Figure 1. Fluent Set-up boundary conditions

- The study aimed to formulate and validate a CFD model under varying throttle settings, relative wind speeds, and wind angles of attack, using actual experimental data as reference.
- These findings are particularly important for assessing operator safety, as they identify specific conditions under which CO concentrations may reach hazardous levels.

METHOD



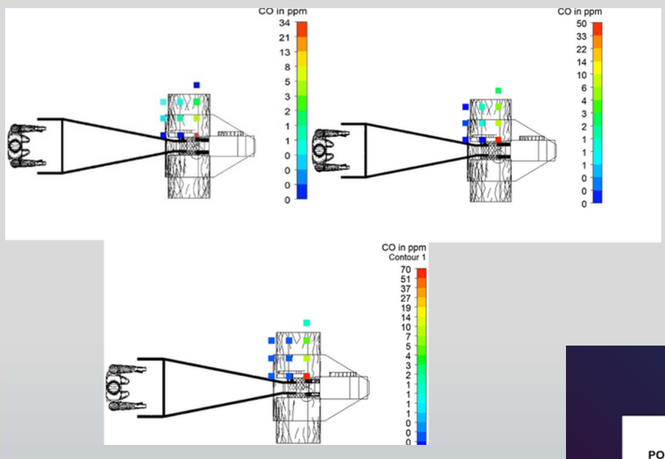




ITEM	SPECIFICATION
Brand	Kuvico
Model	KV70
Type	Diesel
Cooling System	Water-cooled
Maximum	5.1 kW/ 2400
Displacement	376 cm3
Dimensions	48 cm x 24 cm x

- The hand tractor was positioned **stationary and facing the wind tunnel's contraction outlet** to simulate oncoming airflow, with airflow at its location measured for accuracy.
- **Three throttle settings**—idle (650 rpm), mid (1600 rpm), and full (2760 rpm)—were tested to assess engine operating conditions.
- **Exhaust dispersion** was analyzed using ten reference points, including the operator's breathing zone, spaced **20 cm apart** and aligned parallel to the exhaust tailpipe to determine CO concentration profiles

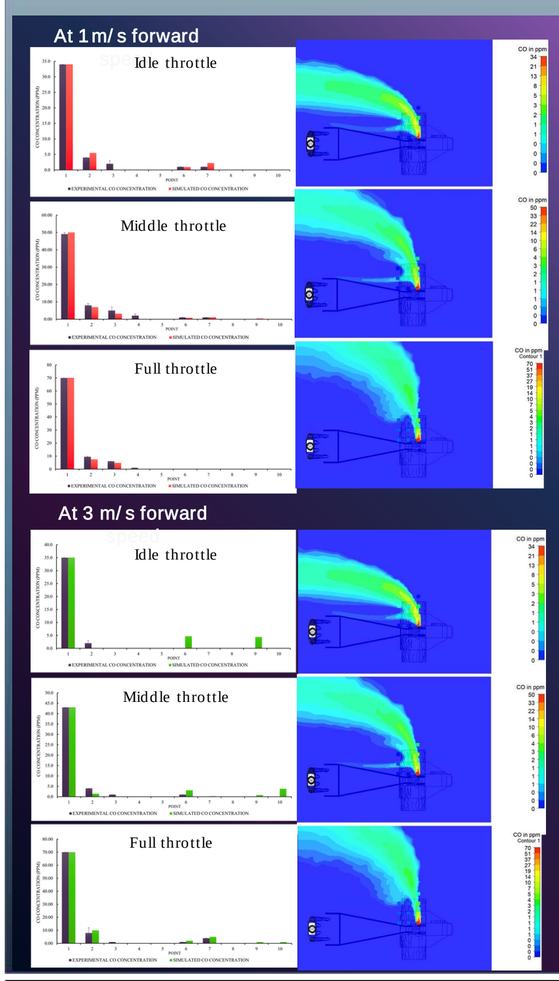
RESULTS & DISCUSSION



- Variation in wind speed influenced the dispersion of CO emissions, with higher wind speeds generally promoting greater dispersion.

- Four turbulence models—standard k-ε, realizable k-ε, standard k-ω, and SST k-ω—were evaluated by comparing simulated CO concentrations at ten validation points and assessing their mean absolute error (MAE).
- The **SST k-ω model performed best** with the lowest MAE (0.39 ppm), followed by **standard k-ω (0.55 ppm)** and **standard k-ε (0.72 ppm)**.

POINT	CO (PPM)	SST K-omega	STANDARD K-omega	STANDARD K-epsilon	REALIZABL E K-epsilon
		SIMULATED CO CONCENTRATION (PPM)			
1	50	50	50	50	50
2	8	7	7	6	6
3	5	3	3	0	0
4	2	0	0	0	0
5	1	0	0	0	0
6	1	1	1	1	1
7	2	1	2	1	0
8	0	0	0	0	0
9	0	0	1	0	0
10	0	0	1	0	0
MEAN ABSOLUTE ERROR		0.39	0.55	0.72	0.78



- Experimental CO data (violet markers) and simulated results at **1 m/s** (red) and **3 m/s** (green) show similar decreasing trends, with error bars reflecting measurement variability due to turbulence and probe sensitivity; both datasets agree well at Point 2 (20 cm from the exhaust).
- The simulation **slightly underestimated CO concentrations** by 1–2 ppm at Points 1–4 under both middle and full-throttle conditions.
- Simulated values aligned closely with experiments along the exhaust's horizontal axis at **1 m/s**, but **larger deviations appeared at 3 m/s**—particularly at Points 6, 7, 8, and 10—indicating regions where the model needs refinement.

CONCLUSION

· The **SST k-ω model** showed the best agreement with experimental data, with strong correlation at **1 m/s** and consistent CO dispersion trends across throttle settings, including an **84–88% drop** in CO concentration at 20 cm from the exhaust.

· The CFD model effectively predicted **CO dispersion under different engine loads and airflow conditions**, highlighting the influence of throttle setting, forward speed, and wind direction on pollutant transport.

FUTURE WORK

· **Enhance measurement accuracy** by using advanced gas analyzers, real-time sensors, improved probing at validation points, and more complete boundary condition data to reduce uncertainties.

· **Improve model realism** through transient simulations and by expanding the analysis to additional pollutants (HC, PM, NOx) for a more comprehensive emission-dispersion assessment.