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Investigation of Welding Fume Plumes Using Laser Diagnostics

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Abstract

In many occupations such as welding, workers are exposed to a combination of several hazards. One of these is the exposure to fumes, particularly those produced from welding processes involving electrical arcs. The inhalation of welding fume can cause both temporary side effects and longer term health complications. These health effects lower the productivity and quality of life of the welder which in turn costs the employer through reduced worker productivity and potential compensation.

Current techniques of fume measurement determine bulk quantity of formation without regard to fume plume dissipation into the work place. While some research has been conducted into dissipation, measurements near the welding arc have proven difficult and either numerical or salt water modelling have been used. Such modelling aims to replicate the welding process but is ultimately detached from the actual welding variables involved and does not provide data on fume concentration. Since welder exposure is determined by both fume concentration and dissipation into the workplace measurement techniques which could provide both would be considered highly desirable.

In the field of combustion research a number of different laser techniques are used to image soot particulates in flames. These techniques include laser scattering, laser extinction and laser induced incandescence. As yet none of these techniques have found application to the measurement or imaging of particulate matter in arc welding fume plumes. In the work presented here these techniques have been investigated for welding fume measurements of concentration and dissipation.

Laser scattering was used successfully to image the fume plume close to the welding arc of actual gas metal and flux cored arc welding processes. The resulting images provided relative fume concentration maps that were quantified when combined with measurements from laser extinction. Laser induced incandescence, while successfully applied to the imaging of soot concentration in flames, was found to have limited capabilities when applied to welding fume particulates.

Fume box measurements were undertaken for GMAW and FCAW to determine actual FFR in response to changes in welding variables. The results were in general agreement with those obtained from laser techniques and referenced in literature.

The fume plume images collected from in-situ laser measurements were compared with those from previous modelling of plume shape, radial spread and virtual origin.

Laser diagnostics demonstrated a number of capabilities not available with traditional fume measurements. The findings of this research provide unique insight into fume dissipation. Such findings can be applied to minimise the quantity of fume, the transmission to the breathing zone and ultimately worker exposure in the workplace.

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Notation

Symbol		Units
A	Area	m^2
Ar_{rad}	Archimedes number	-
Ar_o	Archimedes number origin	-
B	Buoyancy	m^4/s^3
B_o	Buoyancy at origin	m^4/s^3
C_{sca}	Scattering cross-section	m^2
c_1	Volumetric flux constant	-
c_2	Specific momentum constant	-
c_p	Specific heat capacity	$J/kg \times K$
D	Diameter	m
GFR	Gas flow rate	l/min
g	Gravity	m/s^2
g'	Reduced gravity	m/s^2
H	Source to impingement plate distance	m
I_E	Current (electrons)	Amps
I_P	Current (ions)	Amps
I_T	Total current	Amps
I_0	Incident light intensity	J/m^2s
I_t	Transmitted light intensity	J/m^2s
k	Wave number	m^{-1}
L	Intersection path length	m
l_s	Jet/plume length scale	m
M	Specific momentum	m^4/s^2
M_o	Specific momentum at origin	m^4/s^2
m	Mass	kg
MR_v	Volumetric melt rate	m^3/s
N	Number of particles	-
P_{sca}	Power scattered	J/s
Q	Volumetric flux	m^3/s
Q_{sca}	Scattering efficiency	-
q_o	Plume heat input	J/s
q_T	Total heat input	J/s
R_{sp}	Radial spread	m
R_o	Source radius	m
r	Radius	m
Re	Reynolds number	-
T_o	Temperature	K

Symbol		Units
u	Velocity	m/s
V	Voltage	Volts
V_C	Voltage cathode fall	Volts
V_{PC}	Voltage column fall	Volts
V_R	Voltage electrode resistance fall	Volts
V_T	Voltage total	Volts
x	Particle size parameter	-
z_o	Virtual origin	m
ρ	Density	kg/m^3
ρ_∞	Density of the ambient environment	kg/m^3
α	Entrainment constant	-
ψ	Radial spread correction factor	-
φ	Particulate concentration	N/m^3
$\Im$	Scatter intensity at a distance r	J/m^2s
χ_{pix}	Pixel signal count	-
κ	Experimental setup constant	-
Υ	Pixel signal count calibration factor	-
υ	Particulate volume fraction	-
ϕ	Angle of polarisation	rad
θ	Angle of incidence	rad
λ	Wave length	m

Statement of originality

The material in this thesis is original and has not been submitted or accepted for the award of a degree or diploma at any other university and to the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the text of the thesis.

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