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Pollutants Generated by the Combustion of Solid Biomass Fuels

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Foreword

Biomass presents a vast renewable resource that can provide food, energy and chemicals for the worlds' population. The demand for each of these depends on the future development of other technologies and, most importantly, other sources of energy such as nuclear or solar. Progress is also dependent on scientific and technological developments. Firstly, in combustion technology to reduce environmental damage locally, nationally and globally. Improved combustion units are required with higher efficiencies and requiring less maintenance. Biomass will be used for domestic heating purposes on a large scale for some time to come. In order to overcome these emissions problems there are two possible lines of attack. The first lies in the possibility of fuel modification where fuels improved by agronomy or by using genetically modified crops may offer significant advantages. The second involves intellegent fuel blending which may also be advantageous.

There are key issues relating to sustainability in order to provide a constant source of renewable biomass. There are numerous important factors, including the complete utilisation of ash, so that the plant nutrients are sustainable. This is dependent on economic factors and life cycle issues.

It seems likely that the really important developments lie in the large-scale use of biomass electricity production, for heating and chemical production. These processes can also be coupled with carbon capture with sequestration and carbon dioxide utilisation. Such applications present the opportunity for the removal of carbon dioxide from the atmosphere although the magnitude of undertaking this on a substantial scale is enormous. These developments are dependent on engineering solutions such as innovative boiler and furnace designs and intelligent control systems. This will be assisted by computer modelling including virtual biomass plant (CFD) design solutions.

Finally, it should be noted that we have not attempted to describe the history of the development of the understanding of the formation of pollutants from biomass. This is so closely bound up with our understanding of the combustion of gases, hydrocarbon liquids and especially coal that many developments result as a synergy of research activities. Here we have given mainly recent references that also include the preceding literature.

Preface

Recent projections suggest that the world population will be higher than previously estimated and might reach 11 billion by the end of the century (Science, 18 September 2014). The fastest increase is in Sub-Saharan Africa. This projection is higher than that used by the Intergovernmental Panel on Climate Change which assumes a population peak in 2015. Consequently, the population increase will have a greater impact on the amount of energy required for heating, cooking, electricity production, transport, agriculture and the manufacturing industries.

Biomass makes a significant contribution to world energy consumption at the present time, although much of this is for the traditional use of biomass mainly in developing countries. However, it is expected that there will be significant growth in the use of bioenergy using more advanced technology for electricity generation and the provision of heat. Indeed, IEA predicts that the use of bioheat will increase by 60 % by 2035. This will be driven by concerns over climate change and renewable energy policy initiatives by governments. Security of supply issues will play a role because of the wide geographical distribution of biomass. Advances in technology will aid transportation, fuel pre-processing and combustor design.

Issues about resource availability and sustainability are very important. Competition for land potentially leads to food poverty, hence the food versus fuel debate will become extremely important. However, bioenergy presents a number of opportunities for the utilisation of agricultural wastes as solid, liquid and gaseous fuels. The integration of agriculture and bioenergy is an important future requirement.

The combustion of solid biomass will play a major role in these developments but it results in the formation of pollutants which have an adverse effect on the health of the community and on the climate. At the present time there is sufficient concern about these aspects so as to promote more stringent legislation. If the amount of bioheat increases by 60 % over the next two decades, then greater pollution control measures will need to be applied.

In addition, there is the significance of emissions of carbon dioxide resulting from the combustion of biomass. Biomass is potentially almost carbon neutral depending on the agricultural methods. If carbon capture and storage can be applied, then this could reduce the concentration of carbon dioxide in the atmosphere, thus mitigating climate change which would be beneficial to the world as a whole.

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Contents

Acronyms

ASME	American Society of Mechanical Engineers
BS	British Standard
BC	Black Carbon
CEN	Comité Européen de Normalisation
CFD	Computational Fluid Dynamics
daf	Dry ash free
EC	Elemental Carbon
FTIR	Fourier Transform Infra-Red
HHV	Higher Heating Value
ISO	International Organisation for Standardization
LES	Large Eddy Simulation
OC	Organic carbon
PAH	Polycyclic Aromatic Hydrocarbon
pf	Pulverised Fuel
PKE	Palm Kernel Extruder
PM_1	Particulate matter less than 1 μm in diameter
PM_{10}	Particulate matter less than 10 μm in diameter
$PM_{2.5}$	Particulate matter less than 2.5 μm in diameter
PY-GC-MS	Pyrolysis-Gas Chromatograph-Mass Spectrometer
RANS	Reynolds-Averaged Navier Stokes
RCG	Reed Canary Grass
SOC	Soil Organic Carbon
SRC	Short Rotation Willow Coppice
SW	Switchgrass
TGA	Thermal Gravimetric Analyser
TLV	Threshold Limit Value-a measure of toxicity
toe	Tons Oil Equivalent
UBH	Unburned hydrocarbons
VM	Volatile Matter

Nomenclature

A	Pre-exponential factor for devolatilisation
A_p	Surface area of the particle
A_i	Pre-exponential factor
B	Biot Number
C_g	Reacting gas species concentration in the bulk gas
C_1	Experimentally obtained diffusion coefficient
C_{pM}	Specific heat of moisture
D_o	Bulk diffusion rate coefficient
d_p	Particle diameter
D_s	Energy transfer due to species diffusions
E	Activation energy for devolatilisation
E_i	Activation energy for the intrinsic reactivity
F^i	Source term for an external force
F	X_m/M
g^i	Gravitational acceleration
ΔH_M	Enthalpy of vaporisation of moisture
K	Reaction rate constant/turbulent kinetic energy
k_{eff}	Effective rate constant/effective heat conductivity of fluid flow
Kgas	Thermal conductivity, gas
Ksolid	Thermal conductivity, solid
M	Initial moisture content
m_p	Particle mass
N	Dimensionless particle reaction order
Nu	Nusselt Number
P	Pressure
p_{ox}	Partial pressure of the oxidant species in the surrounding gas
R	Process rate/Gas Constant
R_c	R_c is the chemical kinetic reaction rate constant
S	Source term
T_p	Particle temperature
T_∞	Bulk gas temperature

T_{evap}	Evaporation temperature
t	Time
V	Volatile matter, non-dimensionalised
U	Fractional burnout
u^i, etc.	Mean fluid velocity components
X_i	Mol fraction of species i
X_M	Current moisture content

Greek Letters

ε	Dissipation rate
η	Effectiveness factor
ρ	Density
ρ_i	Intrinsic reactivity
μ	Molecular viscosity of fluid flow
τ^{ij}	Reynolds stress tensor
Φ	Related to viscous dissipation

Subscripts

e	Electrical
th	Thermal