ARTICLE IN PRESS

Renewable and Sustainable Energy Reviews ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Prediction of the gas emission from porous media with the concern of energy and environment

Ahmed Al Makky[a], A. Alaswad[c,*], Desmond. Gibson[b], A.G. Olabi[a]

[a] School of Engineering, University of the West of Scotland, Paisley, Scotland
[b] Scottish Universities Physics Alliance, Institute of Thin Films, Sensors & Imaging, Scotland
[c] School of Engineering and the Built Environment, Birmingham City University, England

ARTICLE INFO

Article history:
Received 30 November 2015
Received in revised form
13 June 2016
Accepted 3 August 2016

Keywords:
CO_2
Soil porosity
Permeability
Dynamic chambers
Global warming
Renewable energy

ABSTRACT

Measuring soil carbon dioxide efflux is a challenging task even when it is performed using respiration chambers. While gas samples are taken, measurement deviations become more evident according to the used chamber design especially when external disturbances occur.

This paper studies the carbon dioxide concentration profiles within the top soil layers, and investigates the controlling factors affecting the process. The considered factors are diffusion, temperature and viscosity. The efflux equation is discussed and then it is linked with the soils geotechnical parameters, while a relationship between the Reynolds number within the soil and efflux is found. Emphasis on the importance of the external geometrical design considerations is shown through studying external boundary layer effects due to the chamber outer shell shape and how it interacts with blowing winds. Chamber stability on site of deployment is also of a significant importance considering external blowing winds. Internal geometrical considerations are linked with the flow turbulence within the dynamic chambers. It is highly recommended that respiration chamber designers need to work in parallel with a multidisciplinary team in order to make a chamber design that ensures the least disturbance to occur at the location of study.

Contents

Abbreviations: CFD, Computational Fluid Dynamics; PDE, Partial Differential Equation; IPCC, Intergovernmental Panel on Climate Change; EAHE, Air Heat Exchanger System

* Corresponding author.
E-mail addresses: Ahmed.AlMakky@uws.ac.uk (A.A. Makky), abed.alaswad@bcu.ac.uk (A. Alaswad), Des.Gibson@uws.ac.uk (Desmond. Gibson), Abdul.Olabi@uws.ac.uk (A.G. Olabi).

http://dx.doi.org/10.1016/j.rser.2016.08.001
1364-0321/

Please cite this article as: Makky AA, et al. Prediction of the gas emission from porous media with the concern of energy and environment. Renewable and Sustainable Energy Reviews (2016), http://dx.doi.org/10.1016/j.rser.2016.08.001

1. Introduction

The research work towards developing sustainable and clean energy is advancing through the last four decades as fossil fuels which are widely used as the main energy resources are not sustainable, and significantly linked to the climate change issue. Climate change is increasingly becoming one of the most serious global challenges due to the rapid increase of the greenhouse gases (mainly CO_2, CH_4 and N_2O) in the atmosphere [1,2]. In order to understand the rate of greenhouse gases accumulation and to measure or compare different control proposals, it is very important to measure accurately the greenhouse fluxes between the soil and the atmosphere [3,4]. Soil can be defined as a complex system, consisting of a mixture of organic and mineral particles, soil solution and air, resulting from the interaction between biotic and abiotic factors; it is the medium in which plants acquire water and nutrients through their roots system [5]. This results in a carbon dioxide efflux that flows out and forth from the biologically active soil layers. Due to that the total carbon dioxide efflux is a summation of many sub effluxes. Measuring accurately the production of gas species from the soil is not easy. Spatial variability in soil emissions and the quantification of these emissions is complicated by the high spatial variability exhibited by many microbial processes [6]. This spatial variability is enforced by the soil chemical composition which varies significantly from one location to another [7]. Respiration chambers are used to measure carbon dioxide efflux of location this is through accumulating the gas mixture in an enclosed gas volume within the chamber. Henrik Lundegardh [8] was the first to propose the concept in the form of the respiration bell. Site fertility assessment is the objective whereby carbon dioxide rate of production is the indicator. This means the different soil locations contribute differently to global warming due to difference of site fertility [9]. Consequently with the increase of carbon dioxide concentrations in the atmosphere, planet earth responds to it in the form of the green house affect [10]. This has lead scientists to use numerical nonlinear models to predict future concentrations of carbon dioxide in the atmosphere [11], on the other hand others used more sophisticated models like the dynamic global vegetation model [12] as shown in Fig. 1.

For instance global warming is attributed to burning excessive amounts of fossil fuels [13]. The drive is always to reduce carbon dioxide emissions by lessening the industrial source of the gas. Lessening the production of the carbon dioxide gas requires the reliance on a clean energy source such as wind power as stated by Evans et al. [14]. Human rise of population also contributes in the increase of energy consumption. Therefore using sustainable sources of energy that don't produces carbon dioxide to support the growing demand for energy comes of priority, this if for the case of strategic future planning by governments, as the study by Omer [15] showed for the country of Sudan. Computational hardware and optimization algorithms are developing rapidly. Hence computer software can assist governments in making future plans and predictions to expected energy demands. This is to manage renewable energy sources according to its availability characteristics as shown by Banos et al. [16].

In most African countries forest resources are gradually declining. Hence the supply of fuel wood is becoming more difficult to sustain and demand. Especially that it is already exceeding the potential supply as shown by Bugaje [17]. Therefore governments need to apply policies that make citizens gradually use less fossil fuels [18]. New sustainable source of fuels are being introduced to the global market like the Malaysia palm oil example which is considered one of the most productive bio-diesel crop. Its waste streams can be used to produce vast amounts of bio-gas and other values added products [19]. Another sustainable type of fuel is ethanol which still requires more research to prove its environmental friendliness. This is shown by Niven [20] in his comparison between E10 and E0. Microalgae is another attractive biodiesel fuel that can be considered as a substitute fuel. It is still in the phase of development [21] and the issue of the reduction of its production cost is still posing as a challenge.

A way to asses renewable sources of energy is to apply exergetic analysis on them as shown by Hepbasli in [22]. Life cycle assessment for renewable source of energy is also necessary as stated by Bhat and Prakash [23] for electrical generation systems. Alanne and Saari noted in [24] that energy systems of the future are going to be a mixture of centralized and distributed sub-systems, operating parallel to each other.

In this paper: several efflux models are covered focusing mainly on the physical and geo-mechanical side of the species transport process in the soil with the proposal for the use of a relationship linking efflux with the respiration quotient of a location. A link between efflux and inner soil gas species flow velocity is found through the efflux Reynolds number equation. Furthermore respiration chamber shape and operational mode is covered whereby both are linked with chamber design regulations. For chamber design operational enhancement inner and outer geometrical factors are covered. Likewise the interaction of the chamber outer shell with local boundary layer produced by locally blown winds is discussed. This is for the three used common shapes of cylindrical, box and hemispherical. Lastly a chamber static stability formula is derived for different shapes to assist designer to predict which wind speeds cause chamber tip over.

2. Soil carbon dioxide efflux model

Through the discussion of simple analytical models to calculate carbon dioxide flux in reference [25] stated that 75% of the efflux comes from the top 20 cm of the soil. This means that the atmospheric soil interface is the place to start building the numerical model. Any site location has a set of standard soil layers that have been characterized by geotechnical engineers.

2.1. Chamber gas volume efflux

By considering the most biologically activate ones near the top soil surface can help in modelling the produced efflux. Assuming no external disturbances occur and by applying Fick's first law in the z direction. The considered ideal efflux is the static efflux, which represents a steady case where the species concentration profile does not change with time. Applying Fick's first law on the gas part of the chamber results in Eq. (1.1). Where $ef_{chamber}$ is the gas flux [$\mu mol m^{-2} s^{-1}$]. The term D_{CO_2} is the gas diffusion coefficient for carbon dioxide in the contained air in the chamber [$m^2 s^{-1}$]. Gas diffusion is a function of temperature, once the chamber average temperature is obtained gas diffusion can be found from [26].

$$ef_{chamber} = -D_{CO_2}\frac{\partial Y_{CO_2}}{\partial z} \quad (1.1)$$

Trace gas species concentration Y_{CO_2} [$\mu mol m^{-3}$] is a function of elevation z [m] inside the chamber and can be represented by Eq. (1.2), the distance z_{gs} [m] is from the soil surface to the tip of the gas sensor. The carbon dioxide source term starting from the soil surface is α_s [$\mu mol m^{-3} s^{-1}$], this term incorporates soil bacterial, plant root, and plant leaf activity.

$$Y_{CO_2} = \frac{\alpha_s}{2D_{CO_2}}(z_{gs}^2 - z^2) \quad (1.2)$$

Please cite this article as: Makky AA, et al. Prediction of the gas emission from porous media with the concern of energy and environment. Renewable and Sustainable Energy Reviews (2016), http://dx.doi.org/10.1016/j.rser.2016.08.001