IJMS, *Vol. 18, No. 3-4, (July-December 2019), pp. 285-293*
ISSN: 0972-754X

MATHEMATICAL MODELING OF INDOOR AIR POLLUTANTS DISTRIBUTION FROM BIOMASS COOK STOVES IN NEPAL

Buddhi Prasad Sapkota

SECTION I

1.1 Proposal Outline

Air is one of the five essentials (air, water, food, heat and light) for the human beings. Man breaths nearly 22,000 times in a day that inhales approximately 15kg of air per day. Generally human beings can live 5 weeks without any food, 5 days without any water but not even 5 minutes without air. Even though it is found freely over the surface of the earth, it contains a lot of impurities. Chemically it is composed of (by volume 78.08% (780900 ppm)) Nitrogen, 20.95% (209500 ppm) oxygen, 0.93% (9300 ppm) Argon, 0.032% (320 ppm) Carbon dioxide, 0.0018% (18 ppm) Neon, 0.00052% (5.2 ppm) Methane, 1.2 ppm Krypton, 0.5 mmp hydrogen, 0.5 ppm, 0.08 ppm Xenon, 0.02 ppm Nitrogen dioxide, and 0.001-0.04 ppm Ozone etc. The composition of different pollutants in clean (polluted) air are 0.001-0.01 (0.02-2.0) ppm SO_2, 310-330 (350-700) ppm CO_2, less than 1 (5-200) ppm CO, 0.001-0.01 (0.01-0.5) ppm HC, 10-20(70-700) ($\mu g/m^3$)particulates. (Raju 2005).

In general air pollution means the presence of foreign matter in air. Air pollution is the excessive contamination of foreign matters in the air which adversely affect the wellbeing of the individual or cause damage to property (The American Medical Association). It is the presence of one or more contaminants in outdoor atmosphere in a sufficient quantity and duration to cause them to be injurious to human health and welfare and animal and plant life and to interfere with the enjoyment of life and property. (Dean E. Painter) (Raju 2005).

The study of indoor air pollution (IAP) involves dealing with the emission, accumulation, and assessment of pollutants generally attributed to poor ventilation and air exchange. Of particular concern are issues involving air quality and human comfort within buildings. Toxic fumes and airborne diseases are known to produce undesirable odors, eye and nose irritations, sickness, and occasionally death. Other products such as tobacco smoke and

1st International Conference on Mathematics and Mathematical Sciences (ICMMS), 7 July 2012.

carbon monoxide can also have serious health effects on people exposed to a poorly ventilated environment; studies indicate that indirect or passive smoking can also lead to lung cancer. Recommendations for outdoor airflow rates to dilute indoor polluted air vary considerably. Ventilation systems are designed to either prevent contaminants from entering a room or remove contaminants from interior sources within the room. Since ventilation systems are integral to the study of indoor air pollution, it is prudent to at least identify them. A ventilation system consists of several key components: (1) the contaminant source, (2) an exhaust hood, (3) an air mover, (4) ducts and fittings, (5) makeup air, (6) exhaust air, (7) a pollutant removal device, (8) a discharge stack, and (9) air recirculation. Variations of these components are typically found in most ventilation systems designed to deal with indoor air quality and pollutant removal. In particular, the contaminant source typically consists of particulates, gases, and vapors generated by various activities. An exhaust hood is used to contain contaminants emitted from a source, e.g., hoods are used to cover grills in kitchens, an air mover, or fan, is used to draw air into a hood ducts and fittings make up the piping network connecting the hood to the fan, makeup air is air that is brought into the room from the outside – this air is usually temperature and humidity controlled, exhaust air is the air discharged from the room, a pollutant removal device is a specific piece of equipment used to remove excess contaminant from the room (when environmental standards are exceeded), a discharge stack is a stack that exhausts air into the atmosphere, and air recirculation is air that is returned into the room (clean air). (Peeper 2009)

The major sources of indoor air pollution worldwide include combustion of fuels, tobacco, and coal; ventilation systems; furnishings; and construction materials, fine particles from fuel/tobacco combustion, cleaning operations , cooking, carbon monoxide from fuel/ tobacco combustion, polycyclic aromatic hydrocarbons from fuel/tobacco combustion, cooking, Nitrogen oxides from fuel combustion, sulfur oxides from coal combustion, arsenic and fluorine from coal combustion, volatile and semi-volatile organic compounds from fuel/tobacco combustion, consumer products, furnishings, construction materials, cooking, aldehydes from furnishing, construction materials, cooking, pesticides from consumer products, dust from outside asbestos from remodeling/demolition of construction materials, Lead from remodeling/demolition of painted surfaces, biological pollutants, ventilation systems, furnishings, construction materials and free radicals and other short-lived, highly reactive compounds from indoor chemistry. (Balakishan 2004)

About half of the world's population, mostly in rural areas of Asia, Sub-Saharan Africa and Latin America, still rely on unprocessed biomass as their primary source of domestic energy. Nearly 2 billion kg of biomass such as wood, animal dung and agricultural wastes are burned everyday in developing countries (Barnes 1995), and it accounts for more than 80% of domestic energy in India (Holdren *et al.*, 2000). Biomass fuel refers to plant or animal material used as source of energy. They include wood, charcoal, dung and crop residues such as hay, jute stick, paddy husk, dried leaves, bamboo etc. (NEWS 2009)

Indoor air pollution (IAP) from biomass fuel use is recognized as a significant cause of morbidity and mortality in developing nations including India. Biomass is extensively used for daily household cooking in most of villages in India and Nepal. In addition, biomass is used for room heating in the hilly areas. Particulate matter (PM) having diameter of less than 10 and 2.5 micrometer (PM10 and PM2.5, respectively) are important for eliciting air pollution-related adverse health outcome . (NEWS 2009)

Indoor Air Pollution (IAP) represents the fourth most important health risk factor after malnutrition, unsafe sex and unsafe drinking water and sanitation in the developing world. According to the World Health Organization (WHO), worldwide IAP is responsible for about 1.6 million deaths a year, particularly of young children and women. The major cause of IAP is burning of solid biomass fuels (wood, animal dung and agricultural residues) in open or traditional cook stoves built in poorly ventilated kitchens. More than 80 percent of Nepal's population (approximately 20 million people), principally comprising the rural poor are exposed to dangerous levels of IAP and many people suffer from problems related to IAP. WHO estimates that 2.7 per cent of the national burden of disease in Nepal is attributed to solid fuel use and this causes 7500 deaths per year (WHO, 2007).

Various government and non-government organizations, as well as private companies and international agencies have initiated different programs and introduced a variety of technologies to reduce IAP in Nepal. One of the most simple and popular technologies to reduce IAP in rural homes has been the Improved Cook Stoves (ICS). The mud brick ICS is being promoted by the National ICS Program of AEPC/ESAP along with many other organizations and so far 213059 ICS are installed in phase I of the program and 124069 are installed in 2nd phase till November 2009 with total of 337128 ICS installed in the country such stoves in the country. It has a target of installing 234,000 ICSs in the mid-hills, 200,000 ICSs in the Terai, 50,000 Metallic ICSs in the high mountains, 5,000 institutional ICSs, 10,000 household gasifiers, 1,000 institutional gasifiers till 2012. One of the key elemenet of the program is to conduct an indoor air pollution measurement study. (*www.aepc.gov.np 2011*)

Along with promotion, there is also a need for regular monitoring and evaluation (M&E) in order to verify that the expected impacts in terms of stove performance, IAP reduction and health improvement are actually being realized. M&E can also provide valuable feedback for improving the technology and promotion strategy.

AEPC/ESAP has made a study to assess levels of indoor air pollution in ICS user households before and after installation of ICS; conduct health impact assessment from the measured level of indoor air pollution, especially on women and children; and document and show if installation of ICS has the expected benefits on health and environment. [ENPHO 2008]

Most cooking with biomass seems to be done on cooking stoves that are extremely simple: consisting of three rocks; a U-shaped hole in a block of clay, mud or bricks; a pit in the ground or similar arrangements. In energy content, about 60% of global traditional fuel is wood. The air pollutant emissions from wood combustion depend on type, condition and combustion conditions, but for the low fueling rates typical of household cooking (a few kg per hour), emission factors household cooking (a few kg per hour), are quite significant. (Smith1983)

A cross-sectional survey among 79 Honduran women cooking with traditional or improved cook stoves was made in Honduran Women. Carbon monoxide and fine particulate matter (PM2.5) levels were assessed via indoor and personal monitoring. Pulmonary function and respiratory symptoms were ascertained. Finger-stick blood spot samples were collected to measure C-reactive protein (CRP) concentrations. The use of improved stoves was associated with 63% lower levels of personal PM2.5, 73% lower levels of indoor PM2.5, and 87% lower levels of indoor carbon monoxide as compared to traditional stoves. Women using traditional stoves reported symptoms more frequently than those using improved stoves. There was no evidence of associations between cookstove type or air quality measures with lung function or CRP. (Clarka *et al*., 2009)

1.2 Expected Results, Application and Uses

Study on IAP deals with emission, accumulation and assessment of pollutants generally due to poor ventilation and air exchange. The main concern of such study on IAP concerns with the issue of air quality and human comfort within the building or room and the cost associated with it. Study have shown that indirect and passive smoking can lead to lung cancer. The women in Nepalese kitchen are compelled to leave in a small kitchen without or very nominal ventilation for a long time. Ventilation systems are designed either prevent contaminants from entering a room or remove contaminants from interior sources within the rooms. (Darrel)

Burning firewood for cooking and household heating in winter is the major impacting factor of IAP for the moment. Moreover, type of fuels, status of combustion and ventilation, and house structure can also put an important influence on indoor air quality. For this reason, the level of IAP in rural areas may vary in regions and seasons. The intervention of improved stoves and clean energy can directly and effectively improve indoor air quality. Furthermore, health education, behavior intervention, and social mobilization support to achieve the purpose of improving indoor air quality and in turn change the lifestyle of the people living in risk. (Liu Qin *et al*., 2010)

1.2.1 *Expected Results*

This research focused mainly on developing a model for indoor air pollution distribution will have the following outcomes:

1. Develop a model for indoor air pollution distribution in from cook stoves in Nepal.
2. Comparison of the model with the existing data on IAP
3. Compare this model with the previously developed models of predicting IAP.

Different agencies are involved in the numerical modeling of ventilation and associated interior contaminant transport is still at an early stage of development, considerable amount of research is still needed.

1.2.2 *Applications and Usages of the Research*

Climate change is a hot issue of the international community in recent days. The rural people of Nepal are compelled to live in the highly risky indoor air pollution of the traditional cook stoves. Alternative Energy Promotion Centre/Energy Sector Assistance Program I(AEPC/ESAP) the govt body of Nepal has been implementing the program in Renewable Energy especially in Biomass energy and Improved Cook stove to mitigate this issue. I have been involved in the project as a Team Leader/Regional Coordinator for long time (August 2004 to December 2008). Different researches have been made in this sector like estimation of the indoor air pollution made by the cigarettes, by the vehicles and industries in different parts of the world. In this regard it is my plan to develop a mathematical model to estimate the pollutants of the indoor air pollution in Nepal. Some research has been already and collected data from different parts of the country. The generated data will be studied, analyzed and developed a model with different parameters. The result of the research will be largely used by the development workers, policy makers and the sector agencies and the future researchers. The model can be used for the estimation of the indoor air pollution in the kitchen of Nepal. It will explore the health hazards due to exposure to the indoor air pollution.

1.3 Theoretical Aspect/Conceptual Framework

In recent years there has been extensive activity in the development and use of Computational Fluid Dynamics (CFD) software and special programs for room air movement and contaminant transport applications. These investigations range from the prediction of air jet diffusion, air velocity and temperature distribution in rooms, spread of contamination in enclosures, to fire and smoke spread inside buildings. In most cases the predicted results have been promising when compared to available experimental data. However, numerical modeling of ventilation and associated interior contaminant transport is still at an early stage of development and confidence level. A considerable amount of research and development work is still needed, particularly in the areas of more efficient computational schemes and modeling.

1.3.1 *Mathematical Model*

Indoor Air Quality (IAQ) models provide a way to link information about souces, sinks and building factors to estimate indoor pollutants concentrations. Type of the model used depends on the planned use of the model. The most common uses of IAQ models follow: estimating population exposure to various indoor pollutants, estimating the impact of individual sources on pollutant concentration and estimating the impact of individual sources and IAQ control options on personal exposure. Based on the various uses of IAQ techniques used to develop the model, it is convenient to divide models into three types: Statistical Models, Mass Balance Models and Computational Fluid Dynamics model. (Spark 2004)

There are a variety of analytical tools and simple model configurations that can be useful to a designer in predetermining contaminant levels within an interior. Analytical method, Advection method and Box method are some of the commonly used models. There are different conventional methods of numerical techniques such as Finite Difference Method, Finite Volume Method, Finite Element Methods (one dimensional elements, two dimensional elements and three dimensional elements). Some Advanced techniques like Boundary Element Method, Lagrangian Particle Technique, Particle in Cell, Meshless Method, Molecular Modeling and Turbulent Modeling. (Peeper 2009)

I will use the Mass Balance Models and Monte Carlo Single Box Method in my Mathematical Modeling. Since mass balance model provide the tools best suited for studying general indoor air quality problems. These models can provide good prediction of pollution concentrations and individual exposure under a wide range of concentration. The models allow rapid analysis of indoor air quality control options.

Suitable concerning governing mass balance equations will be developed and used.

1.4 Method and Methodology

Literatures about Indoor Air Pollution, its distribution, mathematical modeling of IAP will be collected and reviewed. Study of diffusion of particle of pollutant in heterogeneous medium will be made, research design will be finalized and development of concerning governing equations will be made. Analysis of the model, study for the simulation of governing equation coupled with relevant parameter, comparative study of the model solution with the experimental data or the result published in previous will make the study method or this research.

The mathematical modeling will be developed through the model creation of the distribution of indoor air pollution in Nepalese kitchen. The data collected by Alternative Energy Promotion Centre/Energy Sector Assistance Program through the research team of ENPHO and other data collected in India and other countries will be checked for the validation of the model. Primary data will be collected thorough the collaboration of AEPC/ ESAP and other agencies like CRT Nepal and other agencies working in the sector. National Network of Regional Renewable Energy Service Centres (RRESCs) will be taken as local level collaborating institutions. The data collected will be tested for validation. Additional contribution will be made on the works made originally in different period of time in Nepalese and international context.

Finite Element Method, Monte Carlo Box Method and Conservation method will be used as a technique for the study. The data generated will be analyzed through the mathematical programing software Matlab with proper programming.

SECTION II
COLLECTION OF BIBLIOGRAPHIES FOR REVIEWS

[1] Balakrishnan Kalpana *et al*., (2004). Indoor Air Pollution Associated with Household Fuel Use in India, The International Bank for Reconstruction and Development/The World Bank, Washington DC, USA.

[2] Balakrishnan Kalpana, *et al*., (2004), Indoor Air Pollution Associated with Household Fuel Use in India, World Bank, 8–9.

[3] Berglund Brigitta *et al*., (1991), Effect of Indoor air Pollution on Human Health, Report No. 10, Environment and Quality of Life, *European Commission of the European Centre, Joint Research committee*.

[4] Clarka Maggie L., *et al*., (2009), Impact of Improved Cookstoves on Indoor Air Pollution and Adverse Health Effects Among Honduran Women, *International Journal of Environmental Health Research*, 1–12.

[5] Environment and Public Health Organization (ENPHO), (2008), Assessment of Effectiveness of Improved Cook Stoves in Reducing IAP and Improving Health.

[6] Goyal P., and Kumar Anikender, Mathematical Modeling of Air Pollutants: An Application to Indian Urban City, Centre for Atmospheric Sciences, Indian Institute of Technology Delhi, India.

[7] Halios C. H., *et al*., (2005), Application of Analytical and Numerical Methods to Indoor Air Experimental Data: Estimation of the Deposition Velocities of the Gaseous Species, *Proceedings of 9th International Conference on Environmental Science and Technology*, Greece.

[8] Halios H., and Helmis G., (2007), On the Estimation of Characteristic Indoor Air Quality Parameters Using Analytical & Numerical Methods, Science of the Total Environment, **381**: 222–232.

[9] Hutzinger Otto, and Austriya Vogel Hub, (2001), Indoor Air pollution, *The Handbook of Environmental Chemistry*.

[10] ICMR, (2001), Indoor Air Pollution In India – A Major Environmental and Public Heath Concern, *Bulletin*, **ol.31**(5).

[11] Indoor Air Quality, (2008), DG Health and Consumers of the European Commission. *http://ec.europa.eu/health/scientific_committees/policy/opinions_plain_language/index_en.htm.*

[12] Johnson Michael *et al*., (2011), Modeling Indoor Air Pollution from Cookstove Emissions in Developing Countries Using a Monte Carlo Single-Box Model, *Atmospheric Environment*, **45**: 3237–3243, *www.elsevier.com/locate/atmosenv*

[13] Kephalopoulos Stylianos *et al*., EC Actions on Indoor Air Quality, European Commission, Joint Research Centre, Institute for Health & Consumer Protection, Physical & Chemical Exposure Unit, Ispra, Italy.

[14] Liu Qin *et al*., (2010). An Overview on Indoor Air Pollution, Its Adverse Health Effects, and Intervention Measures in Rural China, *Conference Paper on ISEE 22nd Annual Conference*, Seoul, Korea, 29–147.

[15] Mishra Vinod *et al*., (2004), Maternal Exposure to Biomass Smoke and Reduced Birth Weight, *Ann Epidemiol 2004*, **14**: 740–747.

[16] Nature Environment and Wildlife Society (NEWS), (2009), Final Report on *Impact of Indoor Air Pollution from Biomass Fuel Burning on Reproductive Health and Neurobehavioral Symptoms of Premenopausal Women in Rural India*, Kolkata.

[17] Neil E. Klepeis, (1999), Validity of the Uniform Mixing Assumption: Determining Human Exposure to Environmental Tobacco Smoke, Environmental Health Perspectives, **107**: 357–363.

[18] Ott Wayne R., (1999), Mathematical Models for Predicting Indoor Air Quality from Smoking Activity, Environmental Health Perspectives **107**: Supplement 2 375, Stanford University, Stanford, California.

[19] Pea Body John Body *et al*., (2005), Indoor Air pollution in Rural China: Cooking Fuels, Stoves and Health Status, *Archives of Environmenatal and Occupational Health*, 86.

[20] Peeper Darrell W., and Carrington David, (2009), *Modeling Indoor Air Pollution*, Imperial College Press, London.

[21] Penton Media inc, (2004), Home Ventilation and Indoor Air Quality, *Nutech Energy System*, In Zimbabwe, Elsevier, USA.

[22] Persily K. Andrew, (1997), Evaluating Indoor IAQ and Ventilation with indoor Carbon Dioxide, *ASHREA Trasactions,* **103**, USA.

[23] Raju B. S. N., (2005), Fundamentals of Air Pollution, Oxford and IBH Publishing Company Pvt. Ltd., New Delhi, 1–2.

[24] Smith Kirk R., *et al*., (1983), Air Pollution and Rural Biomass Fuels in Developing Countries: A Pilot Village Study in India and Implications for Research and Policy, *Atmospheric Environment*, **17**(1) I: 2343–2362, Pergamum Press, Ltd. Great Britain.

[25] Smith Kirk R., (2005), Indoor Air Pollution, University of California, Berkeley, *Environment Matters*, The World Bank Group.

[26] Sparks L. E., (2004), Indoor Quality Modeling, Indoor Air Quality Hand Book, The McGraw-Hill Companies, USA, 58.1.

[27] The World Bank, (2011), Household Cookstoves, Environment, Health, and Climate Change, A New Look at an Old Problem, Washington DC, USA.

[28] Trynor G. W., *et al*., (1982), Effects of Ventilation on Residential Air Pollution, Due to Emission from a Gas-Fired Range, *Environmental International*, **8**: 447–452, USA.

[29] Wayne R. Ott., *et al*., (2003), Analytical Solutions to Compartmental Indoor Air Quality Models with Application to Environmental Tobacco Smoke Concentrations Measured in a House, *Air and Waste Management Association*, **53**(8): 918–936, Departments of Statistics, Stanford University, Stanford.

[30] Zhang J., *et al*., (1999), Carbon Monoxide from Cook Stoves in Developing Countries: Chemosphere: Global Change Science, **1**: 367–375.

Above mentioned & other collected materials will be used to become familiar with the concept, models, mathematical relations, for the purpose of citation on the dissertation, develop the understanding of the subject matter.

Buddhi Prasad Sapkota
Tribhuwan University, Nepal.
E-mail: buddhisapkota@yahoo.com