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Commission on Science and Technology for Sustainable Development in the South

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SCIENCE VISION

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EDITORIAL

It is a matter of satisfaction that the publication gap of Science Vision has gradually reduced. Hopefully, the next volume would be in step with the calendar year. It has been a stupendous effort on the part of the journal s editorial team to sustain the continuity of the journal against heavy odds, in order to fulfill the desire of COMSATS Coordinating Council, which entrusted COMSATS Headquarters in 2009 to revive the journal and to set its focus on articles that reflect the impact of science on society. The shift in the journal s scope, from purely technical articles to those that introduce different disciplines of science and discuss their relevance to the needs of the society, is also gradually taking place. For the benefit of prospective authors, some of the papers in the present issue have been especially written to reflect the desired style and content of the journal s new theme. One of these addresses the question of why is it important to engage in research on plasmas. It gives a simplified but technically sound introduction of plasma physics, and goes on to explain the wide range of situations where plasma science is relevant and its research beneficial for mankind. Similarly, the article on the role of new developments in wireless communications based on photonics is an example of the cross-linkage of scientific disciplines for creating better technologies that eventually benefit all human beings. Such breakthroughs represent the power of technology that needs to be understood and appreciated by the public, and that is what Science Vision strives to achieve.

Five of the articles included in this issue were earlier presented in 2013, during a major biennial international conference organized by COMSATS Institute of Information Technology in Pakistan, bearing the theme 'Environmentally Sustainable Development' (ESDev). Naturally, this theme includes articles in which environmental concerns are addressed while finding scientific solutions to meet the requirements of water, food, health and energy. It is significant to note that nearly all the authors belong to developing countries and their research work is not only of highly quality but is also relevant to the needs of their countries. Their work is also driven by the need to use indigenous natural resources most suited to the specific local conditions. This is not to say that this category of research has only local relevance; in fact, any technology that is environment-friendly has global implications because of the inter-dependence of Earth s ecosystem in different regions of the world. Providing publication space to papers being presented in ESDev series of conferences would remain a policy of Science Vision in the future as well. However, it is to be noted that the journal would not compromise on quality or the peer review mechanism that it has put into place over the last many years. If compromise is inevitable, it is going to be in the publication schedule, but never in the quality of papers that are published.

I take this opportunity to inform the readers that steps have also been taken to constitute a new editorial board comprising international specialists in various scientific and technical fields. This would enhance the quality and outreach of the journal and, hopefully, expand its cohort of contributors.

Last but not the least, it is a pleasant duty to thank all worthy authors for sharing their intellectual labours with Science Vision. Their patronage is highly appreciated and recognized as a noble contribution to propagate scientific ideas for the welfare of mankind. The role that journal s editorial team is playing for the regularity and quality of the journal is highly commendable. Their commitment and hardwork is surely appreciated by all stake-holders of COMSATS.

Dr. I. E. Qureshi
Executive Director COMSATS
Patron & Editor-in-Chief, Science Vision

SCIENCE VISION

Patron and Editor-in-Chief: Dr. Imtinan Elahi Qureshi

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(January to December 2013)

CONTENTS PAGE

WHY STUDY PLASMA SCIENCE

*Shabbir A. Khan**

ABSTRACT

Plasma is an essential stage in the process of formation of matter from elementary particles up to condensed matter. Plasma science is a rapidly growing research field with its natural inter-disciplinary connections from ultrashort scale nanoscience to gigantic scales of astrophysics. The technological applications of plasma science have been ingenious and its influence on scientific progress is significant. That is why the fascinating paradigm of many-body (plasma) physics in classical, as well as quantum mechanical regimes is on the forefront of research nowadays. This article aims to overview the main features of this versatile field with description of its potential technological applications and future promises. It will also help to understand the main reasons of growing interest in plasma science and provide motivation to students to opt it as a future research area.

1. INTRODUCTION

1.1 Plasma: the Fourth State of Matter

The world is undergoing a new revolution fueled by rapid progress in science and technology of the past decades. Principles of fundamental physics which have been known before, from abstract theory, are now suddenly becoming accessible to direct experimental observations and evidences. There are examples of various physical phenomena whose impact on the society has become so vital that these have became separate disciplines of research in physics.

Plasma science encompasses a variety of science disciplines ranging from plasma physics to aspects of atomic and molecular physics, chemistry, and material science. Its broad, interdisciplinary nature also includes ionized gases that range from classical to quantum, cold to hot, weakly ionized to highly ionized, and from collisional to collisionless. These types of plasmas underlie variety of applications and natural phenomena. However, many fundamental considerations dictate the range of parameters from man-made plasmas in laboratories to natural plasma in the universe. The subject is difficult to characterize keeping in mind the diversity of what is included in 'plasma science'. However, its vital contribution to a broad range of applications in scientific & technological developments are due to the same diversity.

Sir William Crookes, an English physicist, identified plasma in 1879. The word 'plasma' was first coined by I. Langmuir and L. Tonks in 1929 for description of oscillations of ionized gases in an electrical discharge. Later on, the definition was broadened to define a state of matter (also known as 'the fourth state of matter') occurring naturally in the cosmos. Generally, plasma is referred to as 'a statistical system of the charged, excited, and neutral assemblies, including some or all of the following: electrons, positive and/or negative ions, atoms, molecules, radicals, and radiation exhibiting collective motion — a joint ping-pong game'. As a whole, a plasma is electrically neutral, because any unbalance of charges would result in the long range electric and magnetic fields. It will, in turn, move the charges in a way it would neutralize charges of opposite sign [1-3].

Plasmas are characterized by various regimes depending upon the distribution of energy and density, which can be described by classical or quantum mechanical models. For instance, the (common) space (e.g., interplanetary and interstellar media) or laboratory (e.g., gas discharges) plasmas are rarefied ionized gases in random thermal motion. On the other hand, the electron gas in metals and semiconductors also behaves very similar to gaseous plasmas. However, there is a basic difference: the relevant statistics changes from (classical) Maxwell-Boltzmann to (quantum) Fermi-Dirac. The quantum electron gas in metals is globally neutralized by the lattice ions whose properties are governed by various control parameters. Similarly, dense low temperature plasmas also obey the Bose-Einstein statistics with no restrictions on the number of particles in the same energy state. Various plasmas found in nature and laboratory can be shown by a simple density–temperature phase diagram (Figure-1) which illustrates regime of density and temperature of different plasma systems[†].

The historical developments and familiar types of plasmas are briefly described as follows.

1.2 Historical Developments

There has been a firm belief that plasma existed since the beginning of the universe. At extremely high

[†] For more details see Ref. 4, 5 & 6

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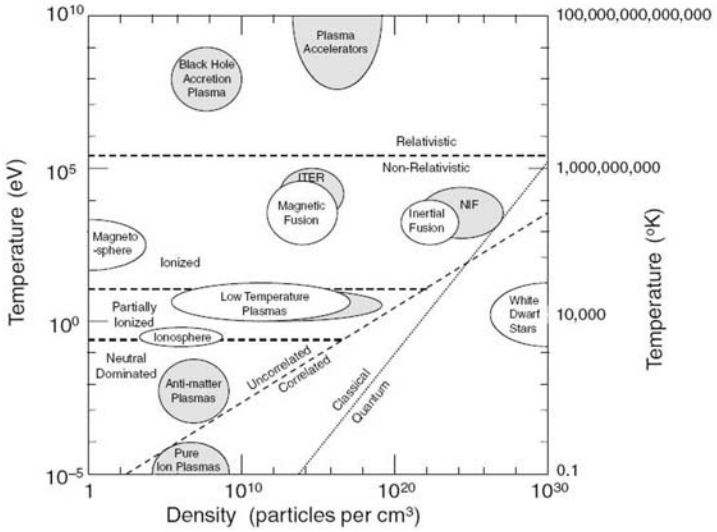

Figure-1: Some Phenomena in the range of plasma physics. Regimes that are new areas of study since 1990 are indicated in gray, including the future regimes of the National Ignition Facility (NIF) and the International Thermonuclear Experimental Reactor (ITER) [Ref. 7]

nuclear densities (~10^{39} cm^{-3}), the physical process like Mott transitions in compressed matter leads to quark-gluon plasma (QGP), a very special kind of plasma interacting via a (color) Coulomb potential. Such plasmas are believed to have existed immediately after the Big Bang and seen in Relativistic Heavy Ion Collider (RHIC) and Large Hadron Collider (LHC) experiments. Ionized matter found naturally in dense astrophysical objects (e.g., stellar cores, white and brown dwarfs, neutron stars, etc.) and interior of giant planets in the solar system (e.g., Jovian planets) constitutes plasma under extreme conditions of density. Here, the electrons may be non-relativistic or relativistic depending upon the electron energy. However, on a terrestrial scales, the developments in plasma physics dates back to early 1920s when plasma started getting recognition with major contributions from the Nobel Prize winning scientist Irving Langmuir, who first used the term plasma to describe the charge dynamics in ionized gas. Langmuir was inspired by the blood plasma which carries red and white corpuscles in the way an ionized gas carries electrons and ions. Langmuir, Tonks, and others also started its first technological inception by finding the ways to extend the lifetime of tungsten-filament light bulbs greatly. In the process, they developed the Theory of Sheaths in Plasmas and well known theory of Electron Plasma Oscillations (now called Langmuir Wave Theory. The field was somehow established in 1930s, and got impetus in 1940s when another Noble Laureate, Hannes Alfven, developed a theory of hydromagnetic waves (now called Alfven en Waves) and revealed its significance in astrophysical settings. This later led to the explanation of some complex phenomena like solar coronal heating, the solar wind interactions in space, the magnetohydrodynamics (MHD) of laboratory systems, and so on. The significance of plasma in the description of theory and experiments on thermonuclear, the creation of thermonuclear bomb, and the idea of sustainable controlled thermonuclear reaction for energy production generated a great deal of interest in the field of plasma physics since 1950s. At first, USA was the main contributor in the research with secrecy due to the observations of the devastative potential of the fusion. In parallel, the work continued independently in the USSR and the UK. In short time, the world recognized the importance of joint efforts in the field, with major emphasis on the peaceful use of fusion for energy discouraging its destructive uses. The institutions like International Atomic Energy Agency (IAEA) were established for coordinated efforts in the right directions. Progress in plasmas again accelerated with the development of tokamak machine by Russians by the end of 1960s. By 1970s and 1980s many tokamaks with improved performance were constructed and fusion breakeven had been achieved in tokamaks[†].

Various new applications of plasma physics appeared

[†] For further details, see Ref. 8.

in 1970s, and were developed as critical technique for the fabrication of the tiny, complex integrated circuits used in modern technology. Plasma processing and plasma treatment are vital technologies used in a large number of industries with hundreds of applications, some of which are described in the next section.

On the other hand, plasma is a natural medium in space and astrophysics. Plasma has been one of the priority area of research in space astrophysics, which has significantly contributed in our current knowledge of planetary and space science. Plasma is operative from very small scales of highly compressed degenerate stars to interstellar and intergalactic scales. The research activities in stellar bodies are the main source of development in space technology, which made possible to launch space missions and satellites for various purposes. The main players of the space game in 1970s were USA, Russia, Europe and China. On the technological side, plasma is the backbone of huge projects like plasma-based space missions, High Frequency Active Auroral Research Program (HAAPRP), Radiation Belt Storm Probes (RBSP), etc., and one of the major areas of observations on board by NASA, International Space Station (ISS), European Space Agency (ESA), etc. [9].

1.3 Occurrences of Plasmas

The existence of plasma and its various types can easily be categorized on the basis of density and temperature parameters, relevant to laboratory and astrophysical regimes. The density-temperature phase diagram (Figure-1) helps in defining two major types of plasmas, laboratory based or astrophysical. It includes low-density plasmas (following classical physics laws) and high-density plasmas (following quantum statistics). Both of these types are found in the universe, including:

i. Aurorae;
ii. Ionospheres, magnetospheres, and interior of planets;
iii. Solar and stellar winds;
iv. Solar atmosphere;
v. Solar and stellar shock regions;
vi. Flux ropes;
vii. Coronal mass ejections in the Sun and stars;
viii. Interstellar media;
ix. Intergalactic media;
x. Supernovae remnants (SNRs);
xi. Astrophysical jets;
xii. Lightning, and ball lightning; and
xiii. Matter in degenerate stars (white dwarf, neutron stars, magnetars).

There are also many types of plasmas produced in laboratory, including:

i. Gas discharge plasmas;
ii. Radiation-beam produced plasmas;
iii. Processing plasmas;
iv. Micro and nano plasmas;
v. Degenerate plasmas;
vi. High-energy-density plasmas;
vii. Complex plasmas;
viii. Fusion plasmas; and so on.

The laboratory plasmas are of particular interest from a technological standpoint (Box-1).

1.4 Description of Plasma

Plasma is truly a many-particle systems with its description in the framework of classical and/or quantum mechanical laws. The mean particle distance is a key parameter in plasmas, which is large in most of the abundant space and astrophysical plasmas. That is why the thermal de Broglie wavelength of plasma species (electron) is negligible as compared to the interparticle distance. So the plasma motion is not influenced by quantum effects and the plasma behavior is classical. Such plasmas can be described by classical physics and classical statistical laws. On the other hand, if it is of the order of or smaller than de Broglie wavelength, the plasma is (quantum) degenerate. In this case, few important and unusual effects like overlapping of the wave functions, Mott-transitions, etc., take place. For classical systems, the Coulomb coupling parameter is the ratio of average potential energy and the average kinetic (thermal) energy. If it is much smaller than unity, the plasma behaves as an ideal gas of charge carriers, otherwise the plasma is collisions dominated and the dynamics of plasma is more complex in nature. For sufficiently cold and dense plasmas, the role of thermal energy is taken over by the Fermi energy, the representative of the degeneracy temperature. The strength of particle correlations is measured by quantum Coulomb coupling parameter or Brueckner parameter. The ideal behavior is reached when Fermi energy is much larger than the (potential) interaction energy, otherwise strong correlations exist and plasma in a system of mutually interacting quantum particles. Since the Fermi energy is density dependent quantity, the quantum plasma state is commonly known as the Low Temperature State as evident from Figure-1. Modeling of quantum (degenerate) plasma is done in the

framework of well know quantum physics models e.g., Schrodinger or Heisenberg models, density matrix theory, quantum field theory, and quantum electrodynamics because strong interparticle interactions at de-Broglie length scale impede the use of conventional classical theoretical models [4, 5, 10, 11]. The computational methods for many-particle problems like classical and quantum Monte Carlo schemes, Path Integral Monte Carlo (PIMC) methods, (time dependent) Hartree-Fock (HF,TDHF) theory, density functional theory (DFT) are very popular models. Its applicability varies from atoms, molecules, solids to classical and quantum fluids, and generalized to deal with many different situations.

The standard description of non-equilibrium plasmas is based on kinetic theory, and classical and quantum kinetic equations (KEs) have been developed. The KEs are the most reliable methods for description of plasmas [12]. Many other methods like non-equilibrium Green's function (NEGF), Kadanoff–Baym (KB) equations, etc., are also able to extract the information on plasma dynamics. Finally, the theoretical progress is significant, however the solution and detailed analysis of KEs or the full description of manyparticle systems have been major challenges from a theoretical perspective for the last several decades.

Owing to the analytical complexity of the quantum kinetic approach, drastically simplified macroscopic models like hydrodynamics are often adopted, which can reproduce the salient features of plasma. However, one has a choice with the alternative of studying a physical problem microscopically with inherent difficulties or macroscopically with less cluttered and simpler approach[†].

1.5 Basic Plasma Science

Plasma science has spawned new avenues of basic science. Notably, plasma physicists were among the first to open up and develop the new and profound science of chaos and nonlinear dynamics. Plasma physicists also have great contribution in the study of aerodynamics and turbulence, playing important role in safe air travel and other applications. The vibrant science of plasmas also has a key role in recent new discoveries that have occurred in plasma medicine, engineering and technology fields, thus bringing the plasma science on the forefront of basic sciences. As plasmas are highly conductive and their response to electric and magnetic fields is rapid, they have been a priority area of research, and plasma science a potential field of interest in future.

2. AREAS OF PLASMA TECHNOLOGY

2.1 Fusion Plasmas

2.1.1 Magnetic Confinement Fusion

Fusion is one of nature's most spectacular processes. Billions and billions of fusion furnaces, the Sun among them (Figure-2), are flaring in the universe, creating light and energy. Through the efforts of scientists over the past seventy years, the physics behind this wonder is now well understood. This provides us the

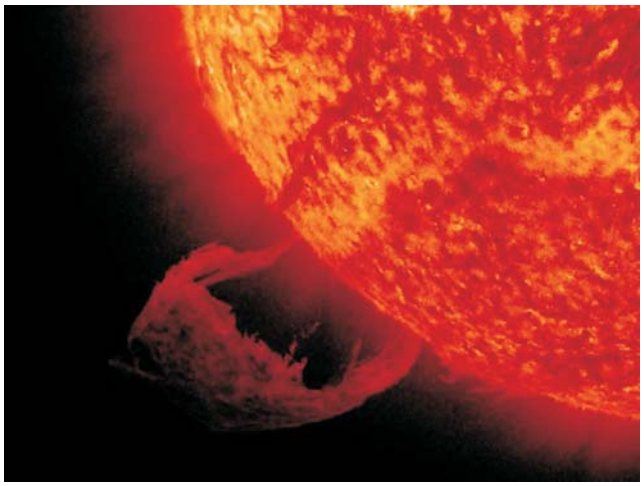

Figure-2: Exploding plasma on the Sun the natural fusion furnace. The eruption is lifting plasma above the Sun s surface. [NASA, www.nasa.gov]

[†] Interested readers of plasma physics can see Ref. 1, 4, 5 & 13 for more details on the description of plasmas.

information of transmutation of the matter in the Sun and stars, which are transforming hydrogen nuclei into helium atoms and releasing tremendous amounts of energy during the process. With this knowledge at hand, the ambition increased to reproduce on Earth a sustainable physical process similar to the ones operative in stars here. But harnessing the energy of the stars was to prove a formidable task, more complex and arduous than anticipated.

Fusion in laboratory demands very small confinement time and very large densities (Lawson criterion) [8]. History of fusion, the experiments started in the 1930s and fusion physics laboratories were established in almost every industrialized country. By the mid 1950s 'fusion machines' were operative on experimental basis in the Union of Soviet Socialist Republics USSR, the USA, UK, Germany, France, and Japan. This helped as similar in understanding of the fusion and associated processes and technologies.

A major breakthrough was achieved in 1968 when researchers in USSR were able to build a doughnut-shaped magnetic confinement device called 'tokamak'. The success was at two levels – achievement of high temperature and plasma confinement times – two of the main criteria to achieving fusion that had never been observed before. It made the tokamak most feasible concept in fusion research and such devices were built in many parts of the world.

Experiments with actual fusion fuel – a mixture of hydrogen isotopes deuterium and tritium started in early 90s in the Tokamak Fusion Test Reactor (TFTR) in Princeton, USA, and Joint European Torus (JET) in Culham, UK, which carried out the World's first controlled fusion power experiment. Sufficiently long-duration controlled fusion was later on achieved in a EURATOM-CEA installation in France and the TRIAM-1M tokamak in Japan and some other machines. JT-60 machine in Japan achieved the highest values of three key parameters in fusion - the plasma density, temperature and confinement time. In these efforts, the scientists have approached the long-sought 'breakeven' point where a device release as much energy as is required to produce fusion.

2.1.1.1 International Thermonuclear Experimental Reactor (ITER) Project: The availability of limitless fusion fuel all over the world; no greenhouse gases; safety; no radioactive waste; large-scale energy production, and above all, the success in getting 'breakeven' point, are the factors that have led to the concept of International Thermonuclear Experimental Reactor (ITER), the world's largest multibillion-euro international nuclear fusion collaborative tokamak project [14]. ITER is a mega-science project of seven stakeholders namely, China, India, Japan, Korea, Russia, USA, as well as European Union aiming to build the tokamak at the Cadarache facility in the South of France. Construction began in 2007, scheduled to be completed in 2020, with first plasma produced in the same year. After resolving all the engineering and science problems (the complicated geometry of machine is evident from Figure-3), the first nuclear fuel – a plasma of two heavy hydrogen isotopes, deuterium and tritium (DT) is scheduled to

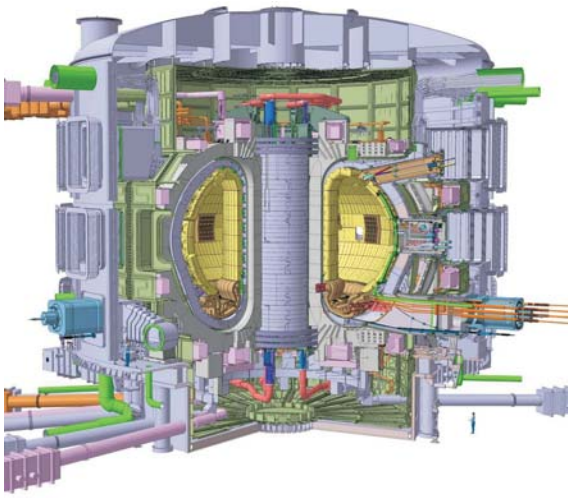

Figure-3: The ITER machine is based on the tokamak concept of magnetic plasma confinement, in which the fusion fuel is contained in a doughnut-shaped vessel. With a height of 29 meters and a diameter of 28 meters, ITER will be the world s largest tokamak. [Ref. 14]

Figure-4: The National Ignition Facility (NIF) is the world s largest laser for inertial fusion purpose. Three football fields could fit inside the NIF Laser and Target Area Building. NIF s 192 intense laser beams can deliver to a target more than 60 times the energy of any previous laser system. NIF became operational in March 2009 and is capable of directing nearly two million joules of ultraviolet laser energy in billionth-of-a-second the target chamber center producing compressed plasma for fusion. [Ref. 15]

be injected into the reactor by 2027 and commercial power production is expected in 2028. Estimated construction, operation and decommissioning cost is 15 billion Euro (~20.3 USD) with design to produce 500 megawatt of fusion power for 50 megawatt of input power for 20 years. If ITER is successful, it could be the first tokamak based power plant to produce more power than it consumes. The ITER team of physicists and engineers has done tremendous job so far and the ITER is hoped to be a game-changing solution for the future energy needs.

In addition to tokamak, alternate plasma confinement and fusion concepts are also hot areas of research nowadays. Some of such concepts include:

- Colliding Beam Fusion;
- Electric Tokamak;
- Floating Multipole;
- Dense Plasma Focus (DPF);
- Heavy Ion Fusion;
- Electrostatic Confinement;
- Matter-antimatter systems;
- Reversed Field Pinch;
- Field Configuration;
- Spheromak;
- Stellarator;
- Spherical Torus;
- Magnetized Target Fusion;
- Tandem Mirror;
- Z-pinch, and more.

The scientists have been pursuing fusion for almost 50 years now. The research in fusion has increased key fusion plasma performance parameters by a factor of 10,000 over 50 years. This in turn leads us to safely say that the progress is now less than a factor of 10 away from producing the core of a fusion power plant. Although the goal of energy production from plasma fusion is somewhat distant, much of the associated science and technologies are being used for commercial purposes today or will be used in a foreseeable future. The current world market for such applications exceeds 100 billion USD per year with a noticeable increase every year.

2.1.2 Inertial fusion

The inertial fusion scheme is based on compressing the gas of deuterium and tritium into a small pellet of glass, or other appropriate material, less than or about one millimeter in size. The pellet is heated by super intense lasers arranged in appropriate geometries. Laser being the highly coherent radiation source has the advantage of being easily focused onto very small spot sizes. In the process of shining laser on a suitable target, some of the laser energy is absorbed by the pellet and a plasma is formed from the outer surface material. This plasma blows out like the gases of a rocket, and causes the remains of the pellet to move inwards with a very high speed. As a result, the deuterium–tritium mixture at the center of the pellet is highly compressed, in turn rapidly igniting the fusion reaction. The pressure generated in this process is

tremendously large which explode the pellet. To sustain the reaction, new deuterium–tritium pellets are then introduced inside the vacuum chamber where the process is repeated again and again. The larger part of the energy in this reaction is carried by the neutrons which are absorbed by some suitable liquid fluid. This fluid is heated by the neutron energy and then is removed by a suitable mechanism to operate a turbine generator for production of electricity.

The inertial confinement fusion (ICF) was first proposed in the early 1970s and now believed to be a practical approach for fusion power generation [16]. Throughout 1980s and 1990s, many experiments around the world took place to understand the complex interaction of intense laser and compressed plasma. However, due to limitations in laser technology, the progress could not result in a practical fusion reactor. Recent advancements in peta and exawatt laser technology like the mega-project of National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL, aerial view shown in Figure-4) [15, 16], Laser Megajoule (LMJ) in France, GSI Germany, and Institute of Laser Engineering (ILE) in Japan has accelerated the progress and hopes for the commercial laser-plasma fusion reactor in future.

2.2 INDUSTRIAL AND COMMERCIAL APPLICATIONS

Plasmas span from laboratory systems of nanometer and even smaller scales to astrophysical and cosmological scales underlying numerous important technological applications for the benefit of mankind as well as our understanding of much of the universe around us. Thus, the long list of plasma applications from electron scale ultrafast phenomena to plasmatechnology-based projects on fusion, aerodynamics, and space probes are not easy to cover in a simple way, for an overview, (Figure-5). The strong links between scientific progress, development, social security, and quality of life are well documented. The contribution of advancement of plasma science in current technology is undoubtedly tremendous and critical to many future developments. The importance of plasma science is evident from huge plasma technology based commercial activity worldwide. In the near past, new plasma technologies

Box-1: Various Types and Applications of Plasmas

Major Areas of Plasma Technology
Plasma processing and thin films
Plasma materials
Plasma diagnostics
Industrial plasmas and applications
Environmental and health applications
Radiation sources and display applications
Space and astrophysical applications
Micro and nanoscale engineering
Plasma health care Plasmonics technology
Plasma chemistry and plasma medicine
High Energy-Density Physics (HEDP)

Space, Astrophysics and Cosmology
Space Weather technologies
Zero gravity plasma probing
Auroral research technology
Radiation Belt probing
Space stations experimentation
Radiation monitoring technology in space missions
Solar and magnetosphere activity monitoring
Space stations observations
Plasma-technology based space probes
Near-planetary and interplanetary data missions
Plasma Jet thrusters for space flights
Propulsion
Electromagnetic and Solar wind measurements
Engineering and technical support projects

Plasma Sheath Phenomena
Spacecraft charging
RF heating
Sheath dynamics
Plasma ion implantation
Plasma probe interactions

Plasma Sources
Laser-produced plasma
Beam-generated plasma
Ion beam sources
Free electron lasers (plasma based)
plasma-generated electron sources
Electron cyclotron (for materials processing)
Parallel plate discharges (materials processing)
Free electron plasma radiation sources
X-ray production (for lithography)
RF sources, electronic (e.g., materials processing)
Coherent microwave sources
Arcs (e.g., steel processing, welding, toxic waste)
Ion engines for space propulsion
MHD thrusters for space propulsion
Neutron production
Plasma production for industrial engineering
Cold atmospheric pressure (CAP) plasmas
One atmosphere gun and filamentary discharges

Plasma Diagnostics
Ion and neutral beam diagnostics
Spectroscopy (mass, photon) and imaging
Probe measurements for density-temperature study
Scattering for remote sensing
Laser-induced fluorescence
Laser transmission diagnostics (e.g., interferometry)
Charged-particle spectrometers

Why Study Plasma Science

Magnetic field measurements
Electric field measurements
Neutral particle analysis
Diagnostics at one atmosphere pressure

Plasma-Based Devices
Plasma opening switches
High-power tubes (thyratrons, ignitrons, klystrons)
Pulsed power systems
Plasma-based light sources
Vacuum electronics
Thin panel displays
Relativistic electron beams (intense X-ray sources)
Plasma channels for flexible beam control
Free electron lasers (tunable)
Gyrotrons (high-power short wavelength)
Backward wave oscillators
Traveling wave tubes
Helicon antennas
Laser self-focusing
Plasma lenses for particle accelerators
Dense plasma focus or pinch plasmas for X-rays and beams
Compact X-ray lasers
Cerenkov grating amplifier
Photon accelerators
Incineration of hazardous materials
Plasma armature railguns
Electron cyclotron resonance reactors
Gas lasers
Arc lamps
Torches and film deposition chambers
Ignition and detonation devices
Meteor burst communication
High-power light sources
Plasma accelerators by relativistic space-charge wave

Wave and Beam Interactions Applications
Externally driven waves
Waves as plasma sources
Waves as diagnostics
Waves as particle accelerators
Beam instabilities (FEL; gyrotrons)
Parametric instabilities
Solitons
Wave-particle interactions
Charged particle trapping
Wave physics research (e.g., electron plasma, upper hybrid,
Low and high frequency mode detection
Ionospheric modification
Light ion beam/plasma interactions
Solar power satellite microwaves
Nonlinear waves
Turbulence, stochasticity and chaos
Striation formation and transport

Plasma Based Computational Resources
Fundamental studies of many-body dynamics
Fundamental studies of Hamiltonian systems
Kinetic theory
Nonlinear systems; nonequilibrium systems
Reconnection
Double layers
Self-organization and chaos
Turbulence
Linkage of micro-, meso-, and macroscale processes

Industrial Plasmas
Thermionic energy converters
MHD converters
Engines, Metallurgy
Catalysts, Spectroscopy
Transformers, Motors, Relays
Reactors, Isotopes
Transistors, IC's
Field-emitter arrays
Lasers, Flashlamps, displays
Plasma surface treatment
Plasma etching
Plasma thin film deposition (e.g.,superconducting film)
Ion interaction with solids
Synthesis of materials (e.g., arc furnaces)
Destructive plasma chemistry
Destruction of chemical warfare agents
Thermal plasmas
Isotope enrichment and separation
Electrical breakdown, switch gear, and corona
Plasma lighting devices
Meat pasteurization
Instrument sterilization
Water treatment systems
Gas treatment
Electron scrubbing of flue gases in substances
Ion beams for fine mirror polishing
Plasma surface treatment
Electron beam-driven fuel injectors
Sterilization of medical instruments
Chemical synthesis
Synthetic diamond films for thin-panel television systems
Plasma chemical processing
low-energy electron-molecule interactions
Low-pressure discharge plasmas
Production of fullerenes
Plasma polymerization
Heavy ion extraction from mixed-mass gas flows
Deterioration of insulating gases

One-atmosphere glow discharge plasma reactor for surface treatment of fabrics (enables improved wettability, wickability, printability of polymer fabrics and wool)

Laser ablation plasmas; precise drilling
Plasma cutting, drilling, welding, hardening
Ceramic powders from plasma synthesis
Impulsive surface heating by ion beams
Metal recovery, extraction, scrap melting
Plant growth
Waste handling, paper, and cement industries
Laser ablation plasmas
Laser and plasma wave undulators for femtosecond pulses of X-rays and gamma rays
Tunable and chirpable coherent high-frequency radiation from
Low frequency radiation by rapid plasma creation
DC to AC radiation generation by rapid plasma creation
Infrared to soft X-ray tunable free-electron laser (FEL)
Optoelectronic microwave and millimeter wave switching
Plasma source ion implantation (PSII)

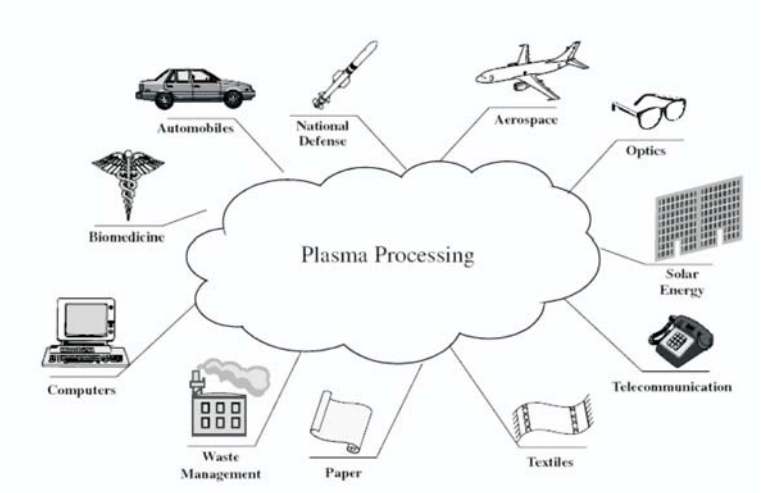

Figure-5: Few Plasma Processing Applications in Industry

01—Plasma TV
02—Plasma-coated jet turbine blades
03—Plasma-manufactured LEDs in panel
04—Diamondlike plasma CVD eyeglass coating
05—Plasma ion-implanted artificial hip
06—Plasma laser-cut cloth
07—Plasma HID headlamps
08—Plasma-produced H_2 in fuel cell
09—Plasma-aided combustion
10—Plasma muffler
11—Plasma ozone water purification
12—Plasma-deposited LCD screen
13—Plasma-deposited silicon for solar cells
14—Plasma-processed microelectronics
15—Plasma-sterilization in pharmaceutical production
16—Plasma-treated polymers
17—Plasma-treated textiles
18—Plasma-treated heart stent
19—Plasma-deposited diffusion barriers for containers
20—Plasma-sputtered window glazing
21—Compact fluorescent plasma lamp

Figure-6: Plasmas in the kitchen. Plasmas and the technologies they enable are pervasive in our daily life. We all touches or are touched by plasma-enabled technologies every day. Various products from microelectronics industry, large-area display systems, lighting, packaging, and solar panels to jet engine turbine blades and bio compatible human implants either directly use or are manufactured with plasmas. They in many cases would not exist without plasmas. The result is a better quality of life and economic competitiveness. Note: CVD, chemical vapor deposition; HID, high-intensity discharge; LED, light emitting diode; LCD, liquid crystal display. [Ref. 7]

have entered our homes, offices, and around (Figure-6).

In the absence of plasma technology, more than 3 trillion USD global telecommunications and semiconductor industry would arguably not exist [7]. Here, we provide a bird's eye view of some of these applications where plasma science is essential ingredient[†].

3. CONCLUSIONS

On Earth, we live on an island of "ordinary" matter which has connections with plasmas in different ways. We have learned to work, play, and rest using the familiar states of matter solid, liquid, and gas but plasma is least known. When considered inclusively, it is clear that plasma science and technology encompasses immense diversity, pervasiveness and potential. Diversity through numerous topical areas; pervasiveness by covering the full range of energy, density, time and spatial scales; and potential through innumerable current and future applications. Thus leading contribution of plasmas in science and technology of 21st century is obvious.

In this article, we have presented an overview of the vast field of plasma science and its technological imprints on society with a brief description of historical developments and occurrences of plasmas. Rather than going into the rigorous discussion on various aspects of plasmas, the basic concepts of plasmas in fusion and other major technological applications have been pointed out. The tremendous activities show that plasma science is on the cusp of a new era making significant breakthroughs in the next decade possible. For example, the giant projects on burning plasmas like ITER, NIF, HiPER, ILE, are expected to take critical steps on the road to commercial fusion. Low-temperature plasma industrial applications are already changing everyday lives. Plasma scientists are on call to help crack the mysteries of exotic universe. This make the dynamic future of the field exciting but challenging at the same time.

The significant contribution of plasmas in technology has made it important to nurture fundamental knowledge of plasma science across all of its subfields. It will make possible to advance the science and to create opportunities for a broader range of science-based applications. Such advancements will play a key role in future national and global priority goals such as fusion energy, economic competitiveness, and industrial activities. The vitality of plasma science also demands transnational efforts for joint ventures on crosscutting plasma research [7].

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PROSPECT OF TREMA ORIENTALIS AS A PULPING RAW MATERIAL IN BANGLADESH

*M. Sarwar Jahan**

ABSTRACT

The pulp and paper industry in Bangladesh is looking for new raw materials with high productivity per hectare. Currently, bamboo and Gmelina arborea are the main pulping raw materials for the pulp and paper industry of the country. Trema orientalis is one of the fastest growing woods in the tropical region. This paper reviews the literature on the topic, in particular, related to the chemical, morphological and physical properties of T. orientalis and its suitability for pulping. In addition, the advantages and disadvantages of various pulping processes proposed in the literature were critically analyzed. It was concluded that T. orientalis is a potential pulp wood for the Bangladesh pulp and paper industry.

Keywords: *Trema orientalis; Physical, Chemical and Morphological properties; Pulping; Bleaching*

1. INTRODUCTION

A growing demand for paper, combined with a declining fiber supply from the forests in Bangladesh, is forcing the pulp and paper industry to find technically and economically viable fiber sources. Although various non-wood fibers may be helpful, wood pulp is still the industry's performance. Forestland in Bangladesh is only 10.2 %, while the population density is very high (FAO, 2009). The use of forestland for the paper industry is decreasing as compared to other land uses. So, it is hard to supply pulpwood from forest to keep the growth of paper industry in the country. In order to achieve this growth, plantation of fast growing species must be established to compensate for the decreasing supply from forests. Fast wood plantation can produce one-and-a-half to two times more wood per hectare per year, and reach maturity two to three times faster than longer-rotation softwood plantations (Cossalter and Smith, 2003). Higher yield of wood reduces the cost of raw material, thus less land is needed to produce the same amount of wood. Environmentalists are also keeping pressure on the industry for preserving forests. So it can be said that restricted access to the natural forest attracts short rotation wood as sources of fibers.

Acacias and Eucalyptus camadonesis are most promising fast growing wood in Bangladesh. The average diameter at barest height (DBH) and height of 4-year old acacia mangium were approximately 24.1 cm and 8 m, respectively (Ogata, et al., 2002). Eucalyptus amplifolia produced 12.8 m height and 17 cm DBH in 53 months (Rockwood, et al., 1995). It was observed in our earlier study that *T. orientalis* is one of the fastest growing trees (Jahan and Mun, 2003). The local name of *T. orientalis* in Bangladesh is Nalita. The fastest growth of *T. orientalis* occurs in warm and moist areas with consistent temperatures. *T. orientalis* is widely distributed through a range of altitudes in higher rainfall areas. It prefers sites on well-drained and exposed soils. *T. orientalis* is also a nitrogen-fixing tree. The average height and DBH of *T. orientalis* was 11.6 m and 21.3 cm at the age of 24 months (Jahan and Mun, 2003.) This species grows naturally in all parts of Bangladesh. Figure-1 shows the tree, brunch, stem and leaves of *T. orientalis* grown in Dhaka region. The picture of stem of three year old *T. orientalis*, indicated that *T. orientalis* is extremely fast growing (Figure-2). Therefore, it may be a suitable source of fiber supply for papermaking in near future (Jahan and

Figure-1: Photograph of *T. orientalis* stem, brunch, leaves and tree

Source: *Jahan and Mun, 2003*

Figure-2: Cross Section of *T. orientalis*

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Mun, 2004).

This review discusses the status and technology of *T. orientalis* pulping and bleaching. The possibilities of commercial production of pulp from this species have also been discussed.

2. PRESENT STATUS OF PULP AND PAPER INDUSTRY IN BANGLADESH

The present status of pulp and paper mills in Bangladesh was elaborately discussed by Quader (2011). Bangladesh Chemical Industries Corporation (BCIC) was a key player in the Bangladesh Pulp and Paper Industry. There were four pulp and paper mills under the umbrella of BCIC, namely: Karnaphuli Paper Mill (KPM), Khulna Newsprint Mill (KNM), North Bengal Paper Mill (NBPM) and Sylhet Pulp & Paper Mill (SPPM). Unfortunately, presently only KPM is in operation, producing quality paper, as well as packaging grade with yearly capacity of 30,000 MT. This mill was commissioned in 1953. One of the main reasons of closing the other three mills was due to the shortage of fiber supply. KNM, a newsprint mill was started in 1959 with an annual capacity of 50,000 MT. This mill used Gewa wood from the Sundarban. UN has declared Sundarban as the world heritage site. Therefore, the government authority stopped the supply of wood to the mills, consequently the mill was forced to shut down. NBPM, a bagasse based pulp mill, was commissioned in 1973 with the annual capacity of 15,000 MT of writing and printing paper. The sugar production in Bangladesh has remarkably decreased. As a result, the bagasse availability also decreased, which led to the closure of NBPM. SPPM, the only pulp mill based on reeds, began production in 1975 with an annual production capacity of 20,000 MT. In addition, BCIC has a joint ownership on the Magura Paper Mill, which produces packaging paper at around 15000 MT per year.

The BCIC's pulp and paper capacity accounted for around 90 % of the Bangladesh's total output some 25 years ago. But today BCIC is producing < 5 % of the total paper products in Bangladesh (Quader, 2011). The private investment in the Bangladesh Pulp and Paper Industry has been significant in the past years, and it dominates the industry, including: T.K. group (paper, board, tissue mill), Basundhar group (paper, tissue, newsprint), Creative paper mill, Capital paper mills, Hakkani paper mill, and Hossain pulp & paper mills.

The per capita paper and board consumption in Bangladesh is about 3.5~4 kg/year, which is much lower than that in a typical developed country (about 300 kg/year/person), and also substantially lower than the Asian average of around 30 kg/year/person. It is expected that the Bangladesh Pulp and Paper Industry could have a rapid increase in the near future.

All of the new mills are using waste paper and imported market pulps. In 2011, Bangladesh has imported about 160,000 MT market pulp at the cost of US$ 128 million, and also imported 424,000 MT paper and paper board (FAO-STAT, 2013). Therefore, it can be concluded that Bangladesh needs more pulp and paper mills to reduce the dependency on imported pulp, paper and paper products.

3. FOREST LAND IN BANGLADESH

The total forest land in Bangladesh is only 1.44 million ha, which accounts for about 11 % of total land area (FAO, 2011). For KPM, 38,000 ha forest land is allocated, where gmelina arborea is planted. This allocated land is controlled by the Bangladesh Forest Department. In addition to this allocated land, there is also a large size of allocated forest land for pulp wood production in Bandarban and Sylhet. The rotation time of G. arborea is 12 year. Unfortunately, this allocated land cannot meet the mill's raw material demand. In this context, there would be a potential to plant a fast-growth wood species, for example, *T. orientalis* that can increase the amount of wood per year per ha.

4. CHEMICAL, MORPHOLOGICAL AND PHYSICAL PROPERTIES OF *T. ORIENTALIS*

The anatomical, chemical, morphological and physical analysis have been reported by Jahan and Mun (2003) in relation to its age, sites and stem and branch (Jahan, et al., 2010). Shown in Table-1 are the chemical, morphological and physical properties of *T. orientalis* stem, which were compared with another potential hardwood in Bangladesh, the rubber wood. The $\propto$-cellulose content in *T. orientalis* was slightly higher than rubber wood (45.0 % vs 42.6 %) and also it is higher than that in typical softwood, but close to that in Eucalyptus (Sjostrom, 1993). The average Klason lignin content in *T. orientalis* was 24 %, which is very close to that from Ku, et al. (1987). The lignin content in *T. orientalis* is higher than that of acacia auriculiformis (Law, et al., 2000), acacia mangium (Santos, et al., 2008) and the Eucalyptus globules (Sjostrom, 1993). The pentosan content in *T. orientalis* is about 23.5 %, which is higher than that in rubber wood. It was found that the total lignin and holocellulose content in *T. orientalis* were increased

Table-1: Chemical, Physical and Morphological Properties of *T. orientalis*

	***T. orientalis* (Jahan, et al. 2010)**	**Rubber wood (Jahan, et al. 2011a)**
Extractives, %		
Acetone	0.89±0.02	0.64
Cold water	2.4±0.3	2.5
Hot water	4.9±0.3	7.9
1% alkali	21.4±0.9	17.1
Lignin, %		
Klason	24.1±1.1	24.1
Acid soluble	2.8±0.2	2.9
Pentosan, %	23.5±1.0	17.1
Holocellulose, %	78.5±1.8	73.8
α-cellulose, %	45.0±1.6	42.6
Ash, %	1.1±0.05	2.5
Density, g/cc	0.368±0.03	-
Fiber length, mm	1.34±0.2	0.96
Fiber diameter, µm	24.5±1.0	22.8

and ash and alcohol-benzene extract decreased from pith to bark (Jahan and Mun, 2003).

Extractives of a raw material are undesirable parts since it affects negatively in pulping and bleaching operations. In general, the extractive content (Table-1) in *T. orientalis* is reasonable, for example, lower than that of Acacia auriculiformis (Law, et al., 2000), and similar to other acacias (Malinen, et al., 2006). The relatively high 1 % alkali solubility in *T. orientalis* may be attributed to the higher amount of low molecular weight polysaccharides, which may result in lower pulp yield.

In the assessment of raw material quality for pulping, wood density is one of the most important parameters. The wood density can have a big impact on the total daily production of a mill (Goyal, et al., 1999). The wood density of *T. orientalis* was 0.368 g/cc (Jahan and Mun, 2003). Ku, et al. (1987) also observed similar wood density of *T. orientalis* from Taiwan. The wood density of *T. orientalis* was lower than the other hardwood species (Isabel, et al., 2001).

Fiber length influences the paper strength, particularly, tear and paper machine runability (Jackson, 1988; Watson and Dedswell, 1961). As shown in Table-1 the fiber length of *T. orientalis* was 1.34 mm, which was in the range of tropical hardwoods (0.7-1.5 mm) (Legg and Hart, 1959). Subramanyam (1987) studied 13 hardwood, including *T. orientalis* and *G. arborea* to evaluate their utility as pulping raw materials, and it was fund that *T. orientalis* was ranked the fifth and *G. arborea* was the last, among these species. It can be mentioned that *G. arborea* is presently being used by Karnaphhul Paper Mill in Bangladesh.

As shown in Figure-3, *T. orientalis* is a rather diffuse porous wood, which consists of fibers, vessels and parenchyma like other hardwoods (Jahan, et al., 2003). As observed in the study, the proportion of fibers and vessel increased with an increase of growth ring (from pith to bark).

5. PULPING OF *T. ORIENTALIS*

T. orientalis was studied for the first time by Shikata and Ogawa as the raw mater for pulping for producing rayon grade pulp using magnesium and calcium-based sulfite pulping processes. *T. orientalis* was readily digested by either process and yields a good quality pulp (Shikata and Ogawa, 1937). In 1953, Bhat and Jaspal (1953) studied this species for paper grade pulp and obtained bleached pulp yield of 46.0-49.8 % by the sulfate process, and the produced pulp could be used for the production of writing and printing papers when mixed with a long-fibered pulp, e.g. from Bamboo. Bhat and Singh (1954) found that *T. orientalis* is a promising raw material for the production of wrapping papers in high yields and of satisfactory

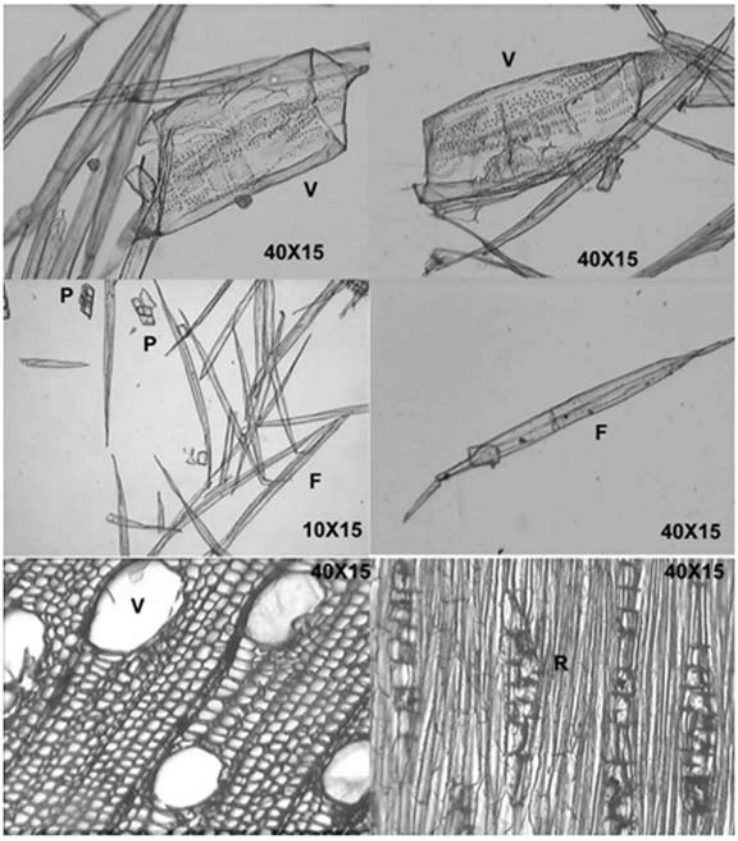

Figure-3: Micrograph of fibers, vessels and parenchyma cells of *T. orientalis* (Jahan and Mun, 2003)

strength. Bhat, et al. (1954) again studied both laboratory and pilot-plant experiments for the production of sulfate and soda pulps from *T. orientalis* and the resulting pulps had satisfactory strength properties, and it was recommended that the pulps should be mixed with a long-fibered pulp in the manufacture of wrapping papers. Hung (1956) studied to use *T. orientalis* for various pulping processes and the low-concentration NH_4HSO_3 process gave a particularly high yield (65%). Chung, et al. (1966) evaluated common Taiwan hardwoods, namely, Lagerstroemia subcostata, Schefflera octophylla, *T. orientalis,* Mallotus paniculatus, Alnus formosana, and Albizzia falcata as the raw materials for four semi-chemical pulping processes, namely, neutral Na-sulfite, cold soda, sulfate, and soda. These processes gave 64 % or higher pulp yield for paperboards and corrugating mediums. Cold soda pulp had the highest yield and lowest cost. It is recommended that the mixture of bleached long fiber pulps and cold soda pulp could be used in making printing papers or newsprint papers. The Na-sulfite pulp could be used in making printing papers. The sulfate and soda pulps could be used in making wrapping papers or bag papers when mixed with kraft pulps. Witayapanyanonta, et al. (1973) studied the kraft pulping of *T. orientalis* at constant 4:1 liquor to wood ratio, 25.5 % sulfidity, variable active alkali content and cooking time, producing screened pulp in 51.2-52.9 % yield, which was further bleached by the CEH sequence, with a yield of 93.3-93.9 %. The writing and book papers were made from these pulps complied fully with the specifications, except for a slight deficiency in pick resistance of book paper. The wrapping paper from the unbleached pulp was deficient in tearing resistance due to relatively short fibers.

For commercial exploration of *T. orientalis* as the raw material for the pulp and paper production, the age of tree on the wood composition, fiber characteristics, wood quality variation with location, anatomy, lignin structure, and the impacts of these factors on pulping would be critical. Extensive R&D program on the pulping of *T. orientalis* has been made, whereby Soda-AQ pulping of *T. orientalis* was evaluated with respect to tree age up to 3 years (Jahan and Mun, 2004). At the age of 3 years, *T. orientalis* produced 48.9 % screened

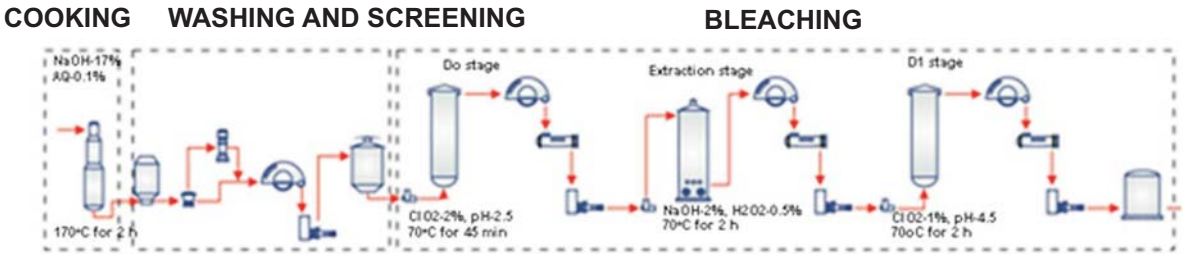

Figure-4: Flow diagram of *T. orientalis* pulping

pulp yield with kappa number 21 under the conditions of 17 % alkali charge, 120 min of cooking at 170°C. *T. orientalis* was also subjected to kraft pulping by varying active alkali and cooking time (Jahan, et al., 2008). Under conditions of 17 % alkali charge, 120 min of cooking at 170°C, the obtained screened pulp yield was 47.0 % with kappa number 20.1. The flow diagram and detail pulping and bleaching conditions of *T. orientalis* pulping in soda-AQ process is given in Figure-4. These results were very close to that of hardwood (Grace and Malcolm, 1993). Effect of different sites and trunk and branch on the pulping of *T. orientalis* was also evaluated and it was found trunk produced better pulp yield than branch (Jahan, et al., 2010). Sites also affect the pulp yield slightly. Different pulping process namely, soda, soda-anthraquinone (AQ), kraft, alkaline-sulfite-anthraquinone-methanol (ASAM), acetic acid and formic acid processes were also evaluated (Jahan, et al., 2007). A good pulp yield (46-52 %), strength and optical properties were obtained in all of these processes. The best pulp yield (51.7 %) and kappa number (13.4) were obtained in the ASAM process under the conditions of 17 % alkali charge at 180°C for 120 min of cooking. The digester pressure in the ASAM process is higher, and the recovery of methanol is another challenge. So the ASAM process is not realistic at this stage. Tear strength of *T. orientalis* pulp was comparatively lower. It was also observed that *T. orientalis* pulp fiber collapsed easily on bleaching, therefore, needs less refining energy to get maximum strength (Jahan and Min, 2004). Strength properties development of *T. orientalis* pulp stops only after ^{0}SR 30. Most of the literature suggested reinforcing softwood pulp for writing and printing grade paper pulp. However, in order to improve the tear strength of *T. orientalis* pulp, longer fiber jute pulp was reinforced (Jahan, et al., 2009). The f-cellulose content in formic acid pulp was greater than 94 %, which suggested further study for dissolving pulp in this process. Therefore, further study was carried out on *T. orientalis* for the production of dissolving pulp and it was found that a good quality dissolving pulp could be produced from *T. orientalis* (Jahan, et al., 2008a).

Recently, interest is growing on the conversion of biomass feed stock into fuel and chemicals, in addition to pulp (Saeed, et al., 2012; van Heiningen, 2006). A promising approach to configuring the forest product biorefinery is to fractionate and convert woody biomass into products, including pulp, extractives such as tall oil, as well as a number of minor products, while the unused biomass fractions, including lignin and hemicellulose solubilized during pulping, will be converted to liquid transportation fuels or other platform chemicals/ materials. In the forest biorefinery concept, pre-pulping extraction has been shown to make available hemicellulose components of the wood while preserving both the yield and quality of the pulp production (van Heiningen, 2006). Forest

Table-2: Comparison of *T. orientalis* and mixed hardwood pulps (Jahan and Mun, 2004; Jahan, et al., 2011a)

Wood species	Pulp yield (%)	Kappa number	^{0}SR	Tensile index (N.m/g)	Tear index (mN.m^2/g)	Burst index (kPa.m^2/g)
T. orientalis	50.0	21.0	30	58.8	7.6	4.8
Mixed hardwood	46.0	20.5	42	50.1	9.3	4.7

products companies may increase revenue by producing biofuels and chemicals in addition to pulp products in an Integrated Forest Biorefinery (IFBR). Therefore, a study was also carried out on the pre-extraction of *T. orientalis* prior to pulp (Jahan, et al., 2011). The pre-extracted liquor (PHL) contained sugars, lignin and acetic acid and these were increased with temperature and time. Pulping of pre-extracted mass was carried out in kraft process. Inferior pulp yield and paper making properties were obtained when pre-extraction was done at higher temperature and time. Pre-extraction at 150°C for one hour followed by kraft pulping showed comparable pulp yield, bleachability and papermaking properties with non-extracted *T. orientalis*, while pre-extracted liquor yielded 3.1 % acetic acid, 1.9 % lignin and 3.5 % hemicelluloses on wood. To implement biorefinery concept, dissolving pulp was also produced from *T. orientalis* (Jahan, et al., 2008a), pre-hydrolysis liquor can be used in producing biofuel, biochemical and biomaterials.

6. BLEACHING

Bleaching can be considered as a final delignification stage of pulp. Bleachability is dependent on the raw material and can be influenced by the conditions in the cooking process (Colodette, et al., 2002; Magnus, et al., 2005). Many attempts have been made to correlate the chemical structure of the residual lignin to the bleachability of the pulp (Tran, 2002; Kumer and Jameel, 1996; Moe, et al., 1998). It was observed that the active alkali and cooking time affect pulp bleachability of *T. orientalis* pulp (Jahan, et al., 2008). At the 19 % active alkali charge and 2.5 h of cooking, the brightness reached to 86.5 % at the Cl_2 consumption of 57.7 kg/MT pulp. In the pulp bleaching process, D_0, D_1 and E stages of bleaching was carried out at 70°C for 45 min, 120 min and 120 min, respectively (Figure-4). *T. orientalis* pulps obtained from the different processes (such as soda, soda-AQ, kraft and ASAM) were studied by D_0ED_1 and QPP bleaching sequences (Jahan, et al., 2007). The oxygen delignified *T. orientalis* pulps gave 76 to 86 % brightness in DED bleaching and 73 to 79 % brightness in QPP bleaching sequences. In the D_0ED_1 bleaching sequences, the brightness of kraft pulp reached to 86.4 % at the ClO_2 consumption of 40 kg/MT pulp (Jahan, et al., 2011). Bleachability of *T. orientalis* pulp also studied in respect to location and within tree (Jahan, et al., 2010). Pulp from Rajbari region showed better bleachability than that of Gaybandha and Dhaka region. Branch pulp responded slightly better bleachability than that of stem pulp. Kraft pulp showed better bleachability than soda-AQ pulp (Jahan, et al., 2010).

7. ECONOMIC EVALUATION OF T. ORIENTALIS PULPING

There was no comprehensive studies carried out on the economics of *T. orientalis* pulping. Kharnaphuli Paper Mills (KPM) is the only running pulp mill in Bangladesh, which uses *G. arborea* as raw material. In the KPM, the raw material cost is 50 % of total production cost. *T. orieatalis* produces 2.5 times wood than the *G. arborea*, which reduces the price of raw materials by at least 25 %. This means 12.5 % pulp production cost is reduced only from raw material. In the laboratory experiment, it was observed that 10 % less chlorine dioxide was required to bleach *T. orientalis* pulp in similar brightness level. Bleaching cost is 25 % of total pulp production cost in KPM. Therefore, total pulp cost is reduced by 6.25 % from pulp bleaching. From the above discussion, it is seen that pulp production cost can be reduced by 18.75 % if *G. arborea* is replaced with *T. orientalis* in KPM.

8. CONCLUDING REMARKS

Trema orientalis is one of the fastest growing species, with acceptable chemical compositions, morphological and anatomical properties to be used as the raw material for pulping. Suitable logging age of this species for pulping is 3 to 4 years, consequently exhibiting a low wood density.

The pulp yield from *T. orientalis* is comparable to that from other hardwood species. Both Soda-AQ and kraft processes are suitable for pulping of this species from the economic and technical points of views. Its bleachability is very good. The resulting pulp is easy to refine, with tensile acceptable for the writing and printing paper grade. Its tear index is slightly lower than the other hardwood species, which can be compensated for by reinforcing longer fiber pulp, such as jute fiber pulp. *T. orientalis* can also be used in the production of dissolving pulp grade. Pre-extraction of *T. orientalis* prior to pulping can extract acetic acid, lignin and hemicelluloses. Therefore, it can be concluded that *T. orientalis* is a potential raw material for the Bangladesh Pulp and Paper Industry, which may replace *G. arborea*.

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PHOTONICS IN WIRELESS TRANSCEIVERS

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ABSTRACT

During the last few years, the cross-fertilization between photonics and radio systems has been helping to overcome some major limitations of the classical radio technologies, setting new paradigms, and promising improved performance and new applications with strong benefits for public communications and safety. In particular, photonics-based wireless systems, albeit still at research level, are moving toward a new generation of multifunctional systems able to manage the wireless communication with several different frequencies and protocols, even simultaneously while also realizing surveillance operations. Photonics matches the new requirements of flexibility for software-defined architectures, thanks to its ultra-wide bandwidths and ease of tunability, and guarantees low footprint and weight, thanks to integrated photonic technologies. Moreover, photonics also allows increased resolution and sensitivity by means of the inherent low phase noise of lasers.

In this paper we review, from a technical point of view, the impact that the demonstrated photonics have in wireless systems, and we consider the related spin-offs for other applications relevant to society. We also describe the first demonstrator of photonics-based multifunctional transceiver presented in Nature Journal (Ghelfi, et al., 2014), that sets a breakthrough innovation in the scientific panorama.

Keywords: *Microwave Photonics, Mode Locking Laser, Wireless Communications, Radar.*

1. INTRODUCTION

Today s wireless communication systems need specific hardware working at specific radio frequencies, with characteristic signal waveforms and bandwidths, requiring dedicated apparatus for each single application. Moreover, next personal communication will need to exploit new frequency bands as the unlicensed millimeter waveband around 60 GHz. The current electronic devices present increasing limitations and poor performance as the frequency gets higher. Similarly, next surveillance systems will require higher carrier frequency for smaller antennas, broadened bandwidth for increased resolution, and software-defined signal generation and detection (the so-called software-defined radio approach, SDR) for flexibility in variable environments (Skolnik, 1980; Haykin, 2006). Therefore, in most of the future transceivers for wireless applications (either communications or surveillance) it will be necessary to generate and receive very stable high-frequencies and wide-band RF signals by means of reliable transmitters/receivers that also respect constraints in size, weight and power consumption (SWaP). Besides this, flexibility and reconfigurability will be another fundamental requirement in tomorrow s systems. For example, in the cognitive radio paradigm, an intelligent radio technology will exploit wide-band receivers in order to automatically detect available channels in a wireless spectrum and constantly monitor the link performance. By adaptively changing the transmission parameters, this technology paradigm will allow to enhance the performance of the whole wireless communications. In the field of radar systems, a new concept of multifunctional radar will be desirable in order to merge in the same apparatus different applications for meteorology, environment monitoring, target detection and communication. In particular, the integration of surveillance and communication functions in a single dual-use system will allow to fully exploit the potentials of its efficiency and flexibility. This functional integration will also enable a reduction of cost and power consumption through the sharing of the same hardware among different functions. Finally, another example concerns the aerospace scenario where the number of applications that rely on satellite navigation systems has strongly increased in the last two decades. Future navigation systems will require even more precise and reliable transceivers in order to offer safety-of-life services and multiple functionalities for reducing the satellite payloads and maximize the satellite life. All of these strategic applications require reduced size, weight and power consumption to enhance their efficiency and effectiveness.

Today s microwave components suffer limited bandwidth, poor flexibility, and high noise at increasing carrier frequencies (Scheer, 1993; Walden, 2008). In conventional electronic RF transceivers, the major limitations comes from the reduced dynamic range due to multiple-stage down-converting mixers, the limited port-to-port isolation at the mixer, and the excessive size, weight, and power requirements of the front-ends. Such front-ends are known to be noisy and suffer from electromagnetic interferences, causing degradation of the sensitivity and of the dynamic range of the final system. These deficiencies are magnified as wider bandwidth systems are developed. Figure-1

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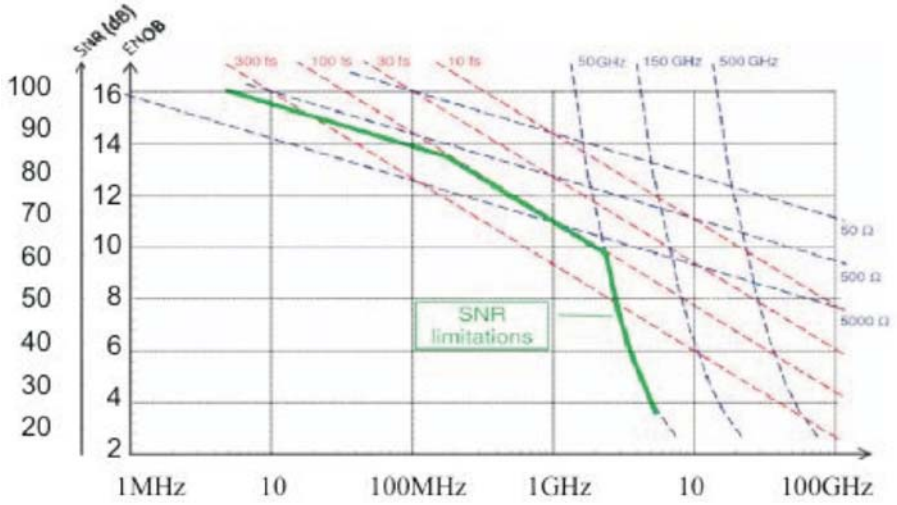

Source: *Piqueras, et al., 2011*

Figure-1: SNR (or ENOB) Limitations of ADCs as a Function of the Input Frequency
The graph reports the main limiting causes for SNR: (i) thermal, shot, and flicker noise contributions, affecting SNR at lower frequencies; (ii) jitter of the sampling clock, affecting the performance at higher frequencies; (iii) ambiguity (or transition frequency), main limitation at highest frequencies. The highlighted green line shows the SNR limits for an ADC with 1kΩ input thermal resistor, jitter of 100fs, and 50GHz of transition frequency.

shows the limits of the signal-to-noise ratio (SNR), or of the effective number of bits (ENOB), for electronic analog-to-digital converters (ADCs) due to different noise contributions, as a function of the input analog bandwidth (Piqueras, et al., 2011). As can be seen, an ADC accepting signal frequencies above 10 GHz with decent SNR (>50 dB) need to show extremely low sampling jitter and very fast switching devices that are hard to be achieved with the current electronic technologies.

On the contrary, photonics has proved high precision and ultra-wide bandwidth (Capmany and Novak, 2007; Yao, 2009), allowing the generation of extremely stable multiple radio-frequency (RF) signals with arbitrary waveforms up to the millimeter waves (Khan, et al., 2010; Ghelfi, et al., 2012), and their detection and precise direct digitization (i.e., without noisy RF down-conversions) (Khilo, et al., 2012; Laghezza, et al., 2013). Up to now, the photonics-based generation and detection of RF signals have been studied only separately and never verified in a radar system. We recently presented the development and the characterization of the first fully photonics-based RF transceiver, which is now being tested in a radar application (Ghelfi, et al., 2014). The proposed architecture exploits a single pulsed laser for both generating and detecting the tunable RF signals, avoiding RF up-/down-conversions and guaranteeing software-defined approach, multiple functionalities, and high resolution, with performance exceeding the state-of-the-art electronics at carrier frequencies above 10 GHz. The foreseen implementation of the proposed architecture by means of integrated-photonics circuits will further increase its potentials, leading to compact and flexible systems suitable for the most requiring future wireless systems.

2. THE PHOTONICS-BASED RF TRANSMITTER AND RECEIVER

In the past few years simple architectures for the photonic generation of RF signals have been envisioned based on the heterodyning of two independent lasers (Goldberg, et al., 1983; Sun, et al., 2006), but these implementations do not allow for a stable RF generation, making the obtained signal not useful for future requiring systems. In order to improve RF stability, phase locking of the beating lasers is necessary, and this usually requires more complex and cumbersome set-ups (Goldberg, et al., 1992). A relatively simple technique for generating phase locked laser lines is the mode locking of lasers (Serafino, et al., 2010; Yilmaz, et al., 2002): the intrinsic phase-locking condition of the mode-locked laser (MLL) ensures an extremely low phase noise of the generated RF signal. Moreover, the possibility of selecting laser modes with variable wavelength detuning allows the flexible production of RF carriers with tunable frequency, potentially generating any

multiple frequency of the MLL repetition rate. Moreover, Serafino, et al., (2010) measured and analyzed the phase noise of the obtained RF carriers, demonstrating that they can be significantly less noisy than the signals generated by the state-of-the-art RF synthesizer.

To implement advanced communication functionalities, the photonics-generated carriers must be modulated into amplitude and/or phase-coded signals via electronics methods, which would require frequency-specific RF components that become more expensive at increasing frequency. An alternative modulation and coding approach based on photonics could instead allow broad RF bandwidth without restrictions on the carrier frequency selection. Few example of this approach have been proposed so far, based on wavelength-to-time conversion (Lin, et al., 2005), on microwave photonic filters (Chi and Yao, 2007), or on the heterodyning of phase modulated continuous-wave lasers (Li, et al., 2011). We have proposed few schemes that exploit the same approach as for the carrier generation, based on the use of a MLL. In the schemes, the modulated RF signal is generated by heterodyning two modes from a MLL, one of which is modulated by the low-pass modulation signal. In this approach, the modulation signal can be generated by a digital synthesizer with narrow analog bandwidth, and directly up-converted by photonic techniques through the heterodyning. Typical Wi-Fi OFDM (orthogonal frequency-division multiplexing) signals and compressed radar pulses have been generated with these techniques, with carrier frequencies up to 40 Ghz. The schemes allow the photonic generation of arbitrary phase-modulated RF pulses with flexible carrier frequency, and phase stability suitable for coherent radar systems. By properly choosing the MLL repetition rate, frequency agility can be also implemented. The carriers can be generated simultaneously or alternately, or even changed continuously. The modulating signal can also be changed meanwhile, implementing a waveform diversity technique.

The receivers for SDR would need high speed ADCs with huge analog input bandwidth spanning over several tens of GHz, and with high spurious-free dynamic range (SFDR) as well as SNR. As described above, precise electronic ADCs show limited analog input bandwidth, since at high input frequency the aperture jitter of the sampling clock affects the accuracy of the digitized signal. Today s best electronic ADCs show an aperture jitter of hundreds femtoseconds with only few GHz of analog BW (Walden, 2008). Optical sampling can overcome the limitations faced by electronic ADCs (Khilo, et al., 2012), and in the last decade several photonics-assisted ADCs have been proposed, based on the electrical detection of modulated optical pulse trains with subsequent sample parallelization schemes. Most of these works resort to the concept of under-sampling to acquire RF signals with bandwidth up to few GHz but carrier frequency up to several tens of GHz. The use of narrow-pulse MLLs with very low temporal jitter guarantees a precise sampling time and a digitized signal with low jitter-limited noise floor. The high electro-optical bandwidth of the optical modulators can broaden the analog input bandwidth of photonic-assisted ADCs up to tens of GHz. Sample parallelization by time- or wavelength-interleaving schemes have been proposed to enlarge the instantaneous bandwidth (i.e., the maximum signal bandwidth) of the photonic ADCs by exploiting a MLL with high repetition rate and a set of parallel low-speed high-precision electronic converters. But the data interleaving can also produce spurious peaks due to the inequalities of the data arrays in the parallel channels, and to the non-idealities of the parallelizing method as time skew and crosstalk (Williamson, 2001). While wavelength-interleaving is most sensible to the time skew, time-interleaving suffers the inter-channels crosstalk due to the limited extinction ratio of the optical switching matrix. Digital post-processing techniques are usually applied to minimize the effect of such spurious components and to maximize the precision of the photonic ADC (Elbornsson, et al., 2005).

We have proposed the exploitation of the time-interleaving approach to avoid the time skew issues, and presented a photonic ADC based on a 4-fold time-interleaving with an extremely low sampling jitter where the limited extinction ratio of the optical switching matrix is compensated for by a real-time digital post-processing reducing the spurious tones (Laghezza, et al., 2013). The realized ADC has shown a state-of-the-art precision above 7 effective bits up to 40GHz with an instantaneous bandwidth of 200 MHZ. The scheme demonstrates to approach the theoretical limit imposed by the sampling jitter, and to be easily scalable to larger signal bandwidth with the current photonic technologies.

3. THE PHOTONICS-BASED RF TRANSCEIVER

The realization of an entire optics-based RF transceiver can therefore exploit a single MLL for both the transmitter and the receiver, thus optimizing the

overall impact of the photonics-based approach in the total system cost. We have followed this approach to realize the first full photonics-based RF transceiver.

We have focused on the specific application to surveillance system. Under this assumption, the carrier frequency of the sampled signal must not coincide with an integer multiple of the sampling frequency, which is unfortunately the case if the RF signal is generated by the beating of two modes from the sampling laser. This constraint can be overcome exploiting the concept of shifting the frequency of one laser mode while maintaining the original phase stability of the MLL. The frequency shift can be realized modulating the mode with a RF oscillator with a small frequency and negligible phase noise compared to the MLL. This is usually the case if low-frequency crystal oscillators are used (Ghelfi, et al., 2011). Moreover, in coherent radars a reference signal is also necessary to detect the Doppler shift on the received echo, and in-phase/quadrature detection must be implemented. The scheme of principle of the realized photonics-based radar transceiver is reported in Figure-2.

The exploited MLL has a repetition rate of 400 MHz, and generates sub-ps pulses with a timing jitter lower than 10 fs (integrated for offset frequencies in the range (10 kHz 10 MHZ). The photonics-based RF generator has been tested producing signals with carriers up to 40 GHz (limited by the photodiode bandwidth) and excellent stability. Modulated RF signals have been also generated directly by using photonic techniques, with broad instantaneous bandwidth potentially ranging up to 200 MHz. The photonics-based ADC has been tested with input continuous-wave (CW) signals in the full range up to 40 GHz, generated by a state-of-the-art synthesizer. The system has reached a precision of 7.4 effective bits for input signal at 10 GHz, and 7 effective bits at 40 Ghz, performing significantly better than the reported electrical ADCs. Moreover, at 40 Ghz the system performance has been measured to be close to the theoretical limit posed by the aperture jitter of 10fs. The test results of the photonics-based transceiver are summarized in Table-1, compared with the performance of the state-of-the-art electronic radar transceivers (Richards, et al., 2010). The advantages of the photonic approach are evident in the extreme frequency flexibility over tens of GHz, in the arbitrary modulation capability, and in the precision of the digitization for any input frequency. These features will enable the SDR paradigm in future radars, as well as in the next generation of flexible wireless communication systems.

The photonics-based transceiver has been inserted in a radar demonstrator with the aim of running field trial

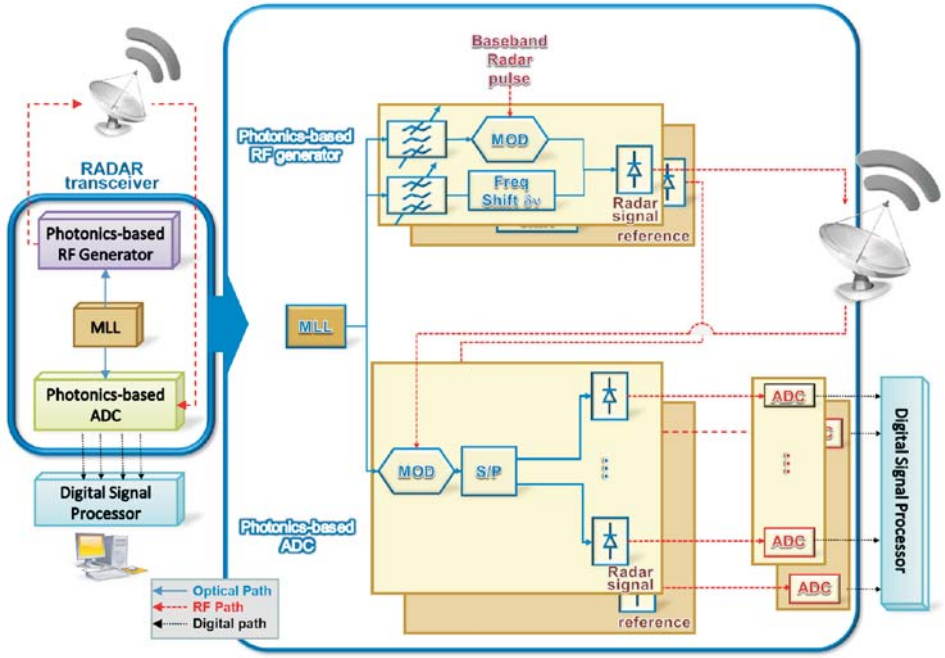

Figure-2: Scheme of Principle of the Photonics-based Transceiver in the Case of Application to Coherent Radars

Table-1: Performance of the Photonics-based Transceiver, Compared with the State-of-the-Art Electronic Transceiver

Parameter	Photonics-based transceiver	State of the art electronics transceiver
Transmitter		
Carrier frequency	Flexible direct generation up to 40GHz	Direct generation below 2GHz up-conversions above 2GHz
Signal jitter	<15fs integrated in [10kHz-10MHz]	Typical >20fs integrated in [10kHz-10MHz]
Signal-to-noise ratio (SNR)	>73dB/MHz	>80dB/MHz
Spurious-free dynamic range (SFDR)	>70dBc	>70dBc
Instantaneous bandwidth	200MHz, easily extendable with MLL at higher repetition rate	<2GHz
Receiver		
Input carrier frequency	up to 40GHz with direct RF undersampling	<2GHz down-conversions at higher frequencies
Instantaneous bandwidth	200MHz, easily extendable with MLL at higher repetition rate	<2GHz
Sampling jitter	<10fs integrated in [10kHz-10MHz]	Typical >100fs integrated in [10kHz-10MHz]
Spurious-free dynamic range (SFDR)	50dB	>70dB
Effective number of bits (ENOB)	>7 for carrier frequency up to 40GHz	<8 for carrier frequency <2GHz

measurements to set its effectiveness in a real application. To this extent, a RF front-end (RF circulator, switches, amplifiers, filters, and bistatic antenna) for a signal carrier at 9,900 MHz is going to be used. Figure-3 reports the results from the recent laboratory trial in a back-to-back configuration, i.e. without launching the radar pulses from the antenna. The system has been set to generate a frequency mismatch between the radar signal and the reference signal, in order to emulate a Doppler shift due to a moving target. Moreover, the radar signal is generated with a delay in order to emulate the distance of the target. Figure-3 (a) shows the calculated distance/velocity map when a target at 5.2 km moving at 83 km/h is detected by means of an unmodulated radar pulse with a duration of 1 μs and a repetition rate of 10 kHz. The zoom in the figure shows a resolution of 150 m in distance and 2 km/h in velocity. Figure-3 (b) reports the distance velocity map in the case of a target at about 9 km approaching at 30 km/h, when the radar is software-driven to generate an RF pulse modulated with a Barker code. As can be seen, the resolution in distance is strongly improved, down to 12 m. Figure-3 (c) and (d) report the distance profile in the case of unmodulated and modulated radar pulse, respectively. The increase in resolution is well evident. The demonstrator will be tested soon in a real environment.

4. COMMENTS AND CONCLUSIONS

The potential of photonics in wireless systems has been revisited, focusing on its spin-offs for applications relevant to society. The first demonstrator

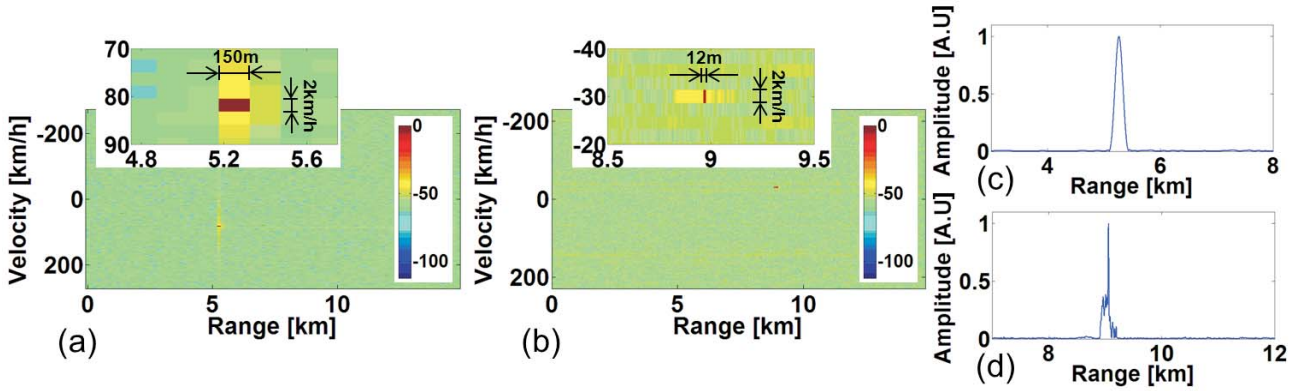

Figure-3: Results from the Back-to-Back Test of the Radar Demonstrator (a): Distance/velocity Map in Case of Unmodulated Radar Pulse. (b): Distance/velocity Map in Case of Radar Pulse Modulated with a Barker code. (c): Distance Profile of Case '(a)'. (d): Distance Profile of Case '(b)'

of photonics-based multifunctional transceiver presented in Nature Journal (Ghelfi, et al., 2014), has also been reported, that sets a breakthrough innovation in the scientific panorama. The characterization of the proposed photonics-based transceiver has highlighted the potentials of photonics to overcome the performance of electronics in terms of flexibility, signal quality, resolution at high frequency, and to enable the SDR and cognitive radio approaches. The proposed photonics-based transceiver has been implemented considering the specific application in a coherent radar system, and to this extent it is characterized by specific features as the frequency shift of the generated carrier and the coherent I/Q detection, which are not required in more generic applications. The radar demonstrator has proved the effectiveness and the expected precision of the photonic solution, which would be fundamental even in wireless communications applications. Nevertheless, an implementation based on dedicated integrated-photonics optical circuits (which is already under development) will fully enable the potentials of the photonic approach, leading to compact and flexible systems suitable for the most requiring applications. For example, photonics will allow the implementation of multifunction systems simultaneously realizing surveillance and communications, also including the signal beamforming in phased-array antennas, and the antenna remotization (Ghelfi, et al., 2013). The photonics-based implementation of additional functions will also bring the positive consequence of further reducing the impact of photonics in terms of cost on the entire system.

From the societal point of view, the availability of multifunction, smart communication/surveillance systems can improve the quality of our lives by flexibly adapting to different protocols, thus reducing the infrastructure costs for wirerless communications, and at the same time by gathering more data with increased precision by means of smaller and greener systems which can be networked together. The larger amount of information can then be used to improve the protection of people from any kind of threat, from homeland security to weather and environment monitoring.

The proposed photonics-based transceiver architecture is therefore expected to open new frontiers in the wireless systems, enabling future smart multifunction communication/surveillance systems that can improve the quality of our lives.

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TELEMEDICINE AS A SOURCE OF UNIVERSAL HEALTH COVERAGE IN PAKISTAN

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ABSTRACT

The combination of information and communication technologies (ICTs) for sustainable healthcare through telemedicine focuses on both changes in the access of healthcare information services as well as wider dissemination of healthcare related skills and professional expertise of medical community. Many developing countries are deficient in healthcare services and suffer from a shortage of doctors and other healthcare professionals. In Pakistan, the inadequate allocation of doctors/specialists, infrastructures of telecommunications, roads and transport make it more difficult to provide healthcare in remote and rural areas. Where clinics and hospitals exist, they are often ill-equipped. The aim of this paper is to share knowledge about the use of telemedic solutions in the health sector in order to propose strategies and actions to formulate tactical recommendations for policy makers and advisors as well as researchers. The examples in this paper illustrate that telemedicine has clearly made an impact on healthcare.

Keywords: *Information and communication technologies, Telemedicine, Healthcare services, Telemedic solutions.*

1. INTRODUCTION

Telemedicine, literally medicine at a distance, is the delivery of healthcare consultations over long distances using medical data shared with information and communication technology. This field takes account of clinical medicine (diagnosis, treatment, and documentation) and academic medicine (research, education, and training). A few features of telemedicine have been in place since the influx of the telephone and have been effectual in limited and rare situations, typically only limited to aiding the delivery of healthcare in remote locations and in bounded support of education and training. Recent advances in information and communication technology and the potential for global communications elevated telemedicine as a serious force in healthcare. Telemedicine now has the potential to make a difference in the lives of many more people, as it can improve the delivery of healthcare in a country by bringing a wider range of services, such as cardiology, radiology, mental health services and dermatology to communities and individuals in underserved urban and rural areas [1]. Fundamentally, telemedicine involves the utilization of modern information technology tools, especially two-way interactive audio/video telecommunications, computers, and telemetry, to deliver health services to patients in remote areas, and to facilitate information exchange between primary care physicians and specialists at distance from each other. A telemedicine system is an integrated healthcare network offering ample health services to a defined population through use of telecommunications and computer technology. Depending upon the level of technology employed, telemedicine can decrease professional isolation of the rural primary practitioner in several ways, e.g. two-way interactive video consultation with specialists links the isolated practitioner with the specialist community of a large medical care. This virtual support system and contact with professional colleagues should increase collaboration between the rural or otherwise isolated practitioner. Telemedicine technology also has the potential to link the primary practitioner with online services, providing them opportunity to evaluate the latest medical literature, thereby strengthening links to the professional medical community and improving the quality of healthcare for the rural population [2].

2. DISCUSSION

The improvement of any technology observably does not occur in a vacuum, making perfect forecasts and predictions even more intricate. The social and cultural milieu may alter, limit, or even prevent development of new ideas and technology development as well as the acceptance and/or implementation of both [3]. Telemedicine systems use a variety of strategies to accomplish monitoring, such as technologies which allow patients to upload monitoring data directly to a healthcare system or to enter it into home computer, whereby it can be transferred to a provider. Further utilization of high-bandwidth phone or cable television infrastructure to apply two-way interactive audio, video, and medical diagnostic instrumentation and the close monitoring, offered by these approaches, may allow better healthcare through early detection of problems or more accurate dosages of medications and biologic agents, potentially reducing costs. Today, telemedicine systems are supported by state-of-the-art technologies like video conferencing; high-resolution monitors; high-speed computer networks and switching systems; and telecommunications superhighways, including fiber optics, satellites and cellular telephony [1]. Store-and-forward telemedicine

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system gather medical data, store it, and then forward it to be examined later. This system provides the ability to capture and store digital, still or moving images of patients, as well as audio and text data. Store-and-forward systems eradicate the need to have the patient and the specialist available at the same time therefore it is an asynchronous, non-interactive form of telemedicine. It is usually employed as a clinical consultation (as opposed to an office or hospital visit). Whereas, home-based telemedicine system enables physicians and health providers to monitor physiologic measurements, test result, images, and sounds, usually collected in a patient s residence or a nursing facility. Home-based telemedicine system also improves patient-provider communication for appropriate treatment and medication. There is also cost saving with the store-and-forward system compared to the real-time method, and the savings come from not needing costly video-conferencing equipment or a high-bandwidth line to support it. This is an important issue, especially in developing countries, where the costs of high-bandwidth Internet connections are very high. An advantage of the store-and-forward method in terms of functionality is that the telemedicine kit (as portable kit shown in Figure-1) can be transported to locations that do not need to have Internet connections. This is an important capability to be used in rural areas, because it allows the health practitioners to make virtual visits to patients homes or to give consultations at a nearby health center and forward the information to a specialist for diagnosis at a later time.

Figure-1: The Portable Telemedicine Kit [Ref. 4]

3. IMPROVING THE FUNCTIONING OF HEALTHCARE SYSTEM

According to WHO, the use of ICT in healthcare is not simply about technology, but a means to reaching a series of desired outcomes, such as [5]:

a) health workers making better treatment decisions;
b) hospitals providing higher quality and safer care;
c) people making informed choices about their own health;
d) governments becoming more responsive to health needs;
e) national and local information systems supporting the development of effective, efficient, and equitable health systems;
f) policymakers and the public becoming more aware of health risks; and
g) people having better access to the information and knowledge they need for better health.

The developing world has comparatively little experience or success with telemedicine because of the high costs associate with internet connectivity, high-end videoconferencing systems and sophisticated peripheral medical devices. Expensive technologies are simply out of the reach of health organizations in developing countries, which may have more immediate priorities (such as providing nutrition, sanitation and vaccinations to the population). To make things worse, developing countries have very high patient-per-doctor ratios [6].

4. NEED OF TELEMEDICINE IN PAKISTAN

Investigation on the impact of ICTs on healthcare discloses an enormous range of opportunities for significant cost reductions and service enhancements, through what is often broadly referred to as tele-health . The four key areas of tele-health applications are:

i) Payer applications including management of government funding and delivery programmes, health insurance and the use of e-commerce and electronic communication to coordinate healthcare organizations and activities throughout the system;

ii) Provider applications including the application of e-health in private for-profit, not-for-profit and public hospitals and clinics, the use of e-commerce and Internet based systems linking and integrating health services;

iii) Practitioner applications including the adoption of practice management tools, clinical tools and online communication systems, telemedicine and remote diagnostics, the use of clinical decision support systems and evidence based care in diagnosis and treatment; and

iv) Patient applications including new forms and locations for care delivery, the emergence of the internet and of informed consumers and of new information and health intermediaries, and the use of online pharmacies.

Pakistan has a vast network of healthcare facilities but, coverage, accessibility, cost and quality of health care remain critical issues. The health care system in Pakistan comprises public as well as private health facilities. In the public sector, districts have been given power of developing their own strategies, programs and interventions based on their local needs. About 70% of the population live in rural areas while the percentage of doctors working in rural areas in only about 22% [7]. The estimated human resource available for healthcare in the country included 139,555 doctors, 9,822 dentists and 69,313 nurses. The current population-doctor ratio is 1,183 patients per doctor and 16,914 per dentist. Health care is also provided to the public through vast health infrastructure facilities now consisting of 968 hospitals, 4,813 dispensaries, 5,345 Basic Health Units, 572 Rural Health Centers and 293 TB Centers. However, the health care system as a whole needs to be strengthened further at all levels.

Pakistan is a third world country where people are, by and large, deprived of proper medical facilities especially those living in remote areas. The correlation of Telemedicine can facilitate the patients and educate the healthcare providers for the purpose of improving patient care. In Pakistan, Professor Rashid Jumma, former Director General, Jinnah Hospital, Karachi and former head of the neuro & surgery department, started telemedicine service in June 2005 in Gambat then Jacobabad, Ghotki and Mirpur Khas. In February 2007, the Electronic Government Directorate, Ministry of Information & Technology, Government of Pakistan, took control of the Telemedicine operation in the four districts of Sindh and also started Telemedicine in the eight districts of Punjab on the VAST network. The project of Telemedicine in Sindh is now being carried out by the cooperation of the Ministry of Information Technology, Government of Pakistan and Engro Chemical, Pakistan [8].

5. CONCLUSIONS

There are still significant gaps in the facts between where telemedicine is used and where its use is supported by high-quality evidence. Further indigenous and targeted research that provides high-quality data will provide a strong contribution to understanding how best to deploy technological resources in health system of Pakistan. The detection of a number of critical requirements for the successful implementation of ICTs projects and programmes in the health sector of Pakistan includes [9]:

a) Purpose, strategies, and scope of services to be provided;
b) Audience, customers, and users (targeted populations);
c) Value of health and healthcare to the individual and community;
d) Current ways to assess individual and collective health problems (community health);
e) Needs of the individual, community, and nation;
f) Institutional user needs and commitments; and
g) Competencies of the organization implementing or hosting the ICTs system.

In remote rural areas, where there are comparatively few doctors, telemedicine can improve access to healthcare through reducing the need for patients or doctors to travel. Pakistan is in an inimitable situation for building its Telemedicine infrastructure with its highly qualified medical practitioners and an emerging technological industry, the country has the opportunity to create a multitude of products and services to furnish this evolving area. Telemedicine has a potential to benefit the Pakistani healthcare system in terms of preventive care and disease treatment.

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INDOLEAMINE 2, 3-DIOXYGENASE: POTENTIAL IN CANCER IMMUNOTHERAPY

Abdul Majid Qureshi, Kaenat Nasir**, Amnah Mahroo**, Bilal Zulfiqar** and Kashif Asghar***

ABSTRACT

Indoleamine 2, 3-dioxygenase (IDO) is a potent immunosuppressive enzyme that has a significant role in different types of cancers. There is evidence that shows its involvement in a number of infectious diseases and auto-immune disorders. In vitro and in vivo studies indicate that 1-methyl tryptophan, being a competitive inhibitor, has shown to actively control the conditions in which IDO is over-expressed. Dendritic cells are the natural site of secretion of IDO in the host immune system. However, the expression takes place only in the presence of tolerogenic signals that lead to suppression of T-cell mediated immunogenic responses. Different therapies are being designed by employing the role of IDO in conditions such as stress, depression, cancer, pregnancy, and organ transplant, which reflect the promising role of this new target in cancer immunotherapy.

1. IDO AN IMMUNOSUPPRESSIVE MOLECULE

Indoleamine 2, 3-dioxygenase (IDO) is a single chain, heme-containing oxidoreductase enzyme that is involved in rate-limiting step of tryptophan catabolism. It has an imperative role in conditions like pregnancy, autoimmunity, infection, neoplasia and other malignancies (Curti, et al., 2009). The first and rate-limiting step in tryptophan catabolism is the oxidative cleavage of 2, 3 double bond in the indole ring (Stone & Darlington, 2002) [Figure-1] and also being the first step in biosynthesis of the central metabolic regulator, nicotinamide adenine dinucleotide (NAD). This reaction is catalyzed by two heme-containing enzymes: indoleamine 2, 3-dioxygenase (IDO) and tryptophan 2, 3-dioxygenase (TDO). The expression of TDO is localized to liver whereas the expression of IDO is found in many tissues of the human body (Grohmann, Fallarino & Puccetti, 2003). This expression is further regulated by an intricate display of signals from the immune system, which will be discussed later in the review. It is found that inhibition of IDO in pregnant mice leads to lethal immune rejection of allogenic fetus. In order to suppress the T-cell responses from mother, IDO is continuously secreted at the fetal maternal interface throughout the pregnancy (Kudo & Boyd, 2000).

IDO protein is an apo-enzyme encoded by Indo-gene. The size of this gene is about 15 kbp and it consists of 10 exons. This is a well conserved gene and is located on human chromosome 8. The promoters of IDO gene contain multiple sequence elements that respond to different types of interferon, especially interferon-gamma, which is the main inducer of IDO expression (Suzuki, et al., 2003).

IDO is an intra-cellular enzyme and it does not exist in extra-cellular form. It is commonly found at maternal-fetal interface of placenta, gut, lymph nodes, spleen, epididymis, thymus and lungs. Normally the areas with large lymphoid compartments and widespread mucosal surfaces are found to have the highest degree of IDO expression (Takikawa, et al., 1986).

In mammals, the excess dietary tryptophan is not catabolized by IDO, but by a liver enzyme, tryptophan dioxygenase, and levels of nicotinamide adenine dinucleotide are maintained by conserving it and not by synthesis. Seminal work done by Munn and Mellor and their colleagues, revealed that IDO suppresses T-cell activation, thus modulates immunity (Mellor and Munn, 2004), this was initially demonstrated in the allogenic pregnancy setting (Munn, et al., 1998). T-cells were shown to be preferentially sensitive to activation of IDO, such that tryptophan depletion suppressed T-cell division and resultantly were rendered unable to become activated by Antigen Presenting Cells (APC). The T-cells are also sensitive to tryptophan metabolites, such as kynurenines accumulated by IDO pathway (Fallarino, et al., 2002), which have been shown to be important for T_{regs} induction and immune suppression (Fallarino, et al., 2006; Munn and Mellor, 2007).

2. ISOFORMS

IDO enzymes have been reported to catabolize L-tryptophan into kynurenine, which is biologically an active metabolite. Two isoforms of IDO include IDO1 and IDO2. In 2002, it was revealed that heme region of IDO1 was characterized as having histidine-iron bond, strong steric interactions and hydrogen bonding imposed by L-tryptophan on di-oxygen, which were reported to be crucial in governing the catalytic activity (Terentis, et al., 2002). The IDO1 crystal structure was revealed in 2006 and the complete chemistry of IDO1 reaction was more clearly determined (Sugimoto, et al., 2006).

Initially it was believed that the kynurenine pathway involving tryptophan degradation in extra-hepatic tissues is governed by IDO1, and similarly only IDO1 was thought to perform immunosuppressive effect

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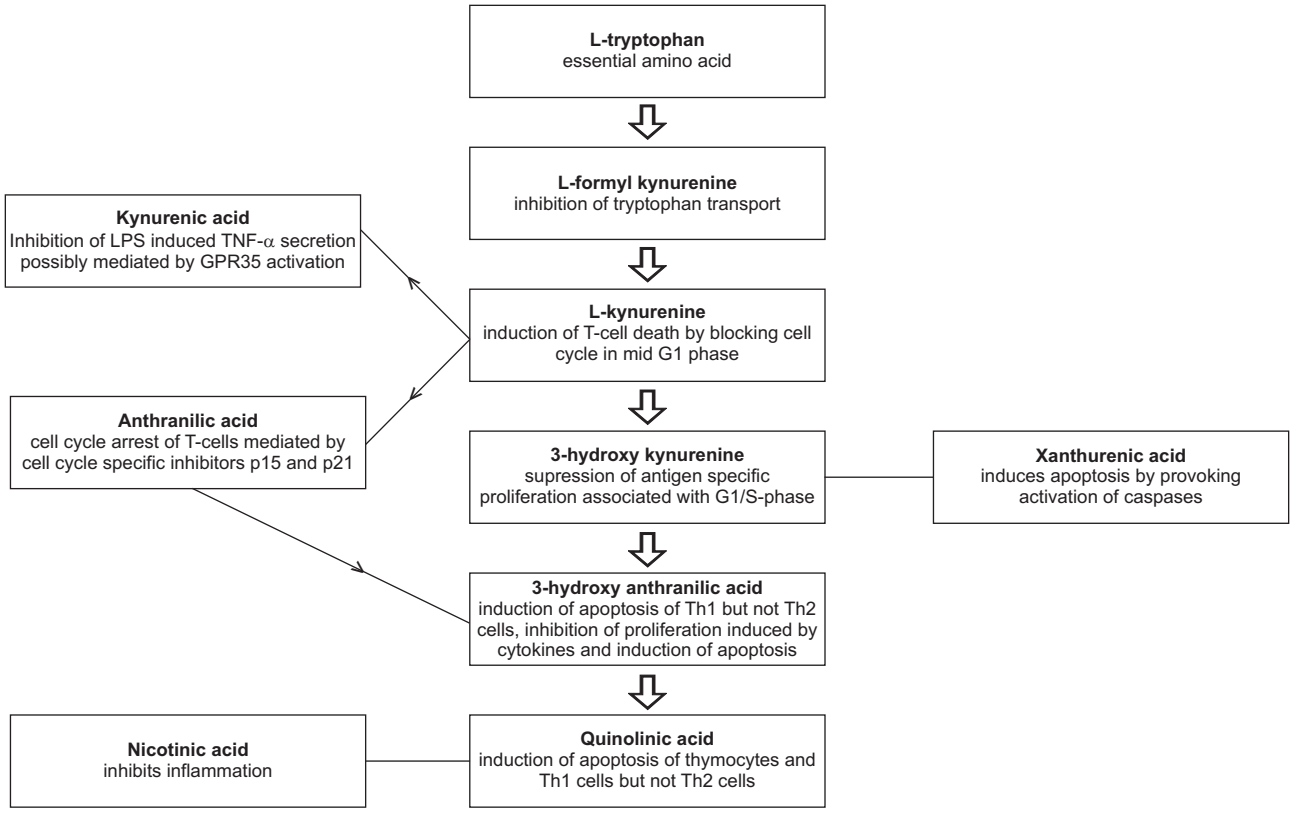

Figure-1: Tryptophan Catabolism Pathway

until recently; however, IDO2, a new isomer and variant was described in 2007 (Ball, et al., 2007; Metz, et al., 2007). The gene responsible for encoding IDO2 is reported to be adjacent to IDO1, and has similar structure as well. These two genes are located at chromosome 8, next to each other in mice as well as humans (Metz, et al., 2007). Both isomers catabolize the same substrate but with different efficiency rate, and show distinct responses while interacting with inhibitors (Lob, 2008; Ball, et al., 2009). Also several reports have shown that the levo isoform of 1MT plays a role in inhibiting IDO1, while D-1MT has shown inhibiting potential against IDO2 (Lob, et al., 2008; Lob, et al., 2009; Ball, et al., 2009).

3. IMMNOSUPRESSION INDUCED BY TRYPTOPHAN DEPLETION

Dendritic cells (DCs) act as the main information management system of the immune system because of their ability to receive a wide array of signals and then determining the type of response needed. When the incoming signals are immunogenic in nature, dendritic cells function to activate the immune system. However, if the signals are tolerogenic in nature like transforming growth factor-β (TGF-β), Interleukin-10 (IL-10) or T-regulatory cells (T_{regs}), the result is modulation of host response against tumor (Andrew & David, 2004). As IDO is found to up-regulate the differentiation of T_{regs}, it is considered to be an operative target for promoting an effective immune response in the state of cancer.

IFN-γ released in response to the Treg induced CTLA-4/B7-dependent T-cell cell-signalling, up-regulates IDO in DCs. Tryptophan degradation caused as a result in the local environment limits the survival and proliferation of T-cells, which otherwise are activated by APCs presenting tumour antigens to them. This process occurs preferentially in tumour draining lymph nodes. In tumour cells IDO expression is super activated by IFN-γ due to BIN1 attenuation (Figure-2), and results in direct suppression of T-cells in local tumour environment.

Research has shown that superoxide ions are a pre-requisite for IDO-mediated tryptophan depletion. This is because the area of infection where leukocytes

actively produce superoxide ions is the prime site for IDO-mediated tryptophan depletion (Hirata & Hayaishi, 1975). In 1984, Pfefferkorn and his coworkers performed some experiments to establish the fact that the growth of intra-cellular parasites can be inhibited by promoting interferon-gamma induced IDO expression. Further, in vitro studies showed that if tryptophan was replenished in the culture media, the conditions would once again become favorable for the growth of infectious micro-organisms. By that time, the role of IDO in limiting the growth of micro-organisms was well established. Later, a new concept appeared on the horizon. According to this, IDO-mediated tryptophan depletion was responsible for regulating the host immune cells. In tryptophan free cultures, T-cells enter the cell cycle but their growth is halted in the mid of G1 phase and they are subjected to apoptotic signals. IDO also has a significant role in suppressing the active immune responses against the allogenic graft. Transfection of IDO to the allograft can prevent or at least delay the immune rejection by sending tolerogenic signals to APCs (Adrian & Angus, 2007).

4. EXPRESSION IN CANCER

Tumor development requires cancer cells to obtain certain characteristics of intrinsic nature, such as resistance to apoptosis, immortalization and self-sufficiency, as well as some cellular extrinsic properties. The latter includes the interaction of tumor cells with immune system that is the most crucial step in determining the transformation of malignant-cells (Curti, et al., 2009). Tumor progression and growth essentially require immune escape (Whiteside, et al., 2006; Gajewski, 2006). Recent studies have shown that IDO is one of the key factors contributing to immunosuppressive strategies induced by tumors (Munn & Mellor, 2007). Various tumor-cell types over-express IDO (Uyttenhove, et al., 2003). IDO protein has been revealed to be involved at both the sites of tumor and draining lymph nodes. At tumor site, the tryptophan depletion, and rise & accumulation of tryptophan metabolites cause loss of effector function and reduce clonal expansion, which result in reduced survival of T-cells. While in draining lymph nodes, plasmacytoid DCs express IDO, thus generating tolerogenic T-cells. In addition, IDO producing DCs have been detected in sentinel lymph nodes of melanoma patients and are associated with poor clinical outcome (Munn, et al., 2004). In humans, correlation of poor prognosis and over-expression of IDO has been reported in endometrial, ovarian and colon carcinoma (Okamoto, et al., 2005; Brandacher, et al., 2006; Ino, et al., 2006). Moreover, in colon cancer, tumoral IDO expression causes reduced tumor infiltration in lymphocytes (Brandacher, et al.,

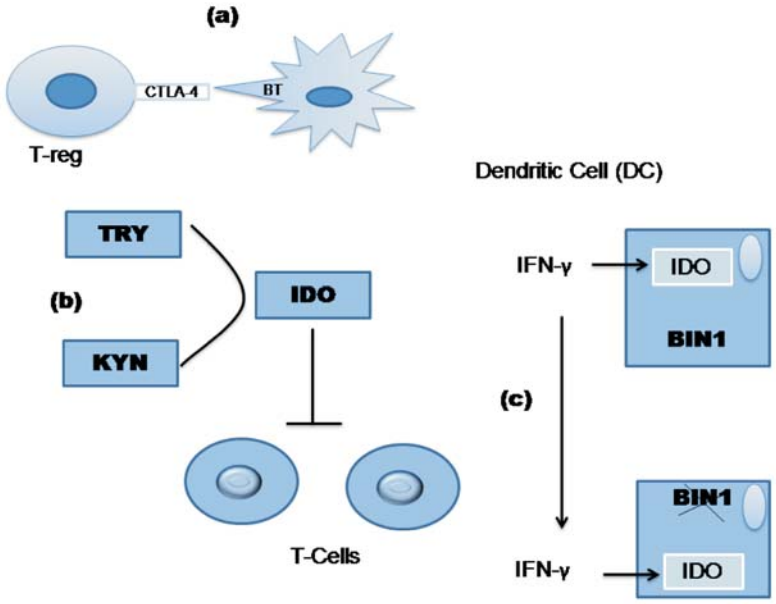

Figure-2: Mechanisms of IDO-Induced Tumor Immune Escape

(a) Treg cells presents tolerogenic signals to the IDO+ cells resulting in release of IDO, which in turn suppresses the T-cell activity; (b) IDO breaks down the essential amino acid tryptophan into kyneurine and inhibits the immunogenic activity if T-cells; (c) IFN-gamma induced IDO expression can be blocked in presence of BIN1

2006). Recently, it has been demonstrated that BIN1, the tumor suppressor gene, has genetic control of IDO expression and is reported to be down regulated in various human cancers. BIN1 loss, might account for pathological condition of IDO deregulation through super-induction of IFN-gamma mediated Indo-gene expression (Muller, et al., 2005).

Studies have shown high expression of IDO in advanced ovarian cancer, and poor patient survival has been associated with it. In addition, it has been demonstrated that overexpression of IDO increases peritoneal tumor dissemination in vivo (Inaba, et al., 2009).

A recent study has revealed that high IDO expression correlates with clinical stage of breast cancer, and therefore plays a very important role in suppressing the immune system in such patients (Sakurai, et al., 2005). The proposed mechanism of immunoregulation that facilitates metastasis is achieved by elevated IDO levels, which results in local T-cell immune suppression in the tumor microenvironment (Brandacher, et al., 2006). The infiltration and amplification of CD4+CD25+T_{regs} promotes and facilitates metastasis and can be related to poor prognosis of cancer (Jinpu, et al., 2011).

Higher cases of lung cancer have reported expression of IDO1, but no significantly determined correlation has been found between expression of IDO1 and clinico-pathological parameters. Immunohistochemical analysis of non-small-cell lung cancer has shown that IDO is not expressed by tumor cells but are instead expressed by eosinophilic granulocytes. There is significant correlation found between IDO expressing infiltrate and overall survival rate determined by analysis of follow-up of lung cancer patients. IDO has been reported as a prototype that bridges vascularization, inflammation and immune escape in order to promote primary, as well as metastatic growth of tumor (Smith, et al., 2012).

Similarly, the BAR-adapter encoding gene BIN1 has a very important role in cancer suppression (Sakamuro, et al., 1996; Elliott, et al., 1999; Ge, et al., 1999; Ge, et al., 2000; Tajiri, et al., 2003). BIN1 gene controls the sub-cellular movement of STAT and NF-κB, which in turn monitors the expression of Indo-gene. The reason behind it is that the afore-mentioned transcription factors are required for the activation of the promoters of Indo-gene. If BIN1 is deleted, the expression of Indo-gene remains unchecked resulting in a high and persistent expression of interferon-gamma induced IDO expression.

5. INHIBITORS

A wide range of bioactive inhibitors has been screened for their activity against IDO due to its crystal structure. There are two major classes of IDO inhibitors, competitive inhibitors and non-competitive inhibitors. 1-methyl tryptophan (1MT) is the key competitive inhibitor of IDO. Since its discovery in 1991, 1MT has been the most studied inhibitor of IDO because of its favorable pharmacokinetic activity like low protein binding, oral availability and low clearance. It works tremendously in retarding the growth of tumor cells when given in combination with potent chemotherapeutic agents, such as cyclophosphamide, cisplatin, doxorubicin or paclitaxel. To date, there have been no cases of toxicity reported against 1-methyl tryptophan, except dehydration in a study performed on experimental mouse model. 1-methyl tryptophan was administered to mice through drinking water (Uyttenhove, et al., 2003).

There are two stereo-isomers of 1-methyl tryptophan: D-isomer and L-isomer. It was found that the L-isomer has highest degree of efficacy when tested *in vitro* on HeLa cell lines and other cell lines or cell free assays. On the contrary, the efficacy of D-isomer was found to be almost equal to that of L-isomer when tested *in vivo* in mouse model and humans. The main reason for the superior activity of D-isomer *in vivo* is that L-isomer did not promote a high level of T-cell proliferation as activated by D-isomer. 1MT has emerged as a promising small molecule inhibitor of IDO over several clinical trials, data suggests that 1MT is synergistic with chemotherapy (Muller, et al., 2005) and as IDO regulates the reprogramming of T_{regs} into TH-$_{17}$-like T-helper cells in tumour draining lymph nodes in part, via CGN2-mediated suppression of IL-6 expression, therefore, is also synergistic with vaccines against established tumors.

Non-competitive inhibitors of IDO are mainly beta-carboline derivatives, which bind to the heme portion of IDO and compete with oxygen to bind to the active site iron. A large number of beta-carboline derived inhibitors has been developed but the fact that these inhibitors behave as benzodiazepine ligands; plays a limiting role in their development. This is because the binding of beta-carboline to the benzodiazepine receptors increase the chance of occurrence of effects caused by Central Nervous System (CNS) permeation

in cancer patients (Muller, 2005). In case of competitive or non-competitive inhibition of IDO, the basic mechanism of inhibition is independent of indole ring substitution. Lately research is being carried out on the development of such potent IDO inhibitors that work by substituting the indole ring of IDO.

6. COMPLIMENTING CANCER THERAPY

Tumor development and immune system involve dynamic and complex interactions. On one side, inflammation presents a pro-tumorigenic microenvironment and immune suppression can sometimes actually result in tumor regression in some models (Erdman, et al., 2004), while on the other side, cancer cells are subjected to evade immune response elicited by tumor antigens (Dunn, et al., 2004). Hence the development of immunotherapeutic strategies have predominately focused on supplementing and stimulating the effector cells of immune system. It is becoming apparent that in cancer patients, immune tolerance is the dominant factor and it will be essential to first breach the immunosuppressive processes in order to make immunotherapy effective (Zou, 2005).

Tryptophan depletion is being recognized as an essential factor in establishing tumor microenvironment that down regulates immune response. The proposed process of immune suppression is tryptophan catabolism in tumor tissues governed by IDO (Platten, et al., 2012).

Immune escape provides an essential gateway to malignancy. The emergence of this attribute of cancer shows the collapse of immune surveillance, an essential, multi-armed and potent way of cancer suppression that critically influences the ultimate clinical outcome of an early tumor stage. Immune escape may act as central modifier of clinical consequences by affecting progression versus dormancy, promoting invasion mechanisms, metastasis, and regulating therapeutic response. Although limited studies have been done until now, suppression of immune system and its escape presents potential areas of research and therapy.

It has emerged through recent evidence that activation of IDO pathway occurs during cancer progression and that may act as a modifier nodal pathway for cancer immune escape. IDO inhibitors have been reported to enhance the efficacy of chemotherapy in mouse model and a lead compound has already entered the phase-1 of clinical trials as an IDO inhibitor. New perspectives in this area of research offer promising ways to target advanced cancers, where pivotal support is provided by immune escape (Prendergast, 2008).

A recent development in mechanistic aspect of immune escape has been the finding of an interface with metabolic alterations that is another attribute of cancer. Furthermore, important mechanisms contributing immune tolerance to cancer antigens have been identified, which involve degradation of arginine and tryptophan by arginase-I and IDO, respectively (Bronte and Zanovello, 2005; Muller, et al., 2005b; Muller and Prendergast, 2007; Munn and Mellor, 2007; Popovic, et al., 2007).

BIN1 attenuation occurs in several human cancers, including prostate, breast, colon and lung cancers, melanoma and neuroblastoma (Ge, et al., 1999; Ge, et al., 2000a, 2000b; Tajiri, et al., 2003; Chang, et al., 2007a). By knocking out gene in the mouse, it has been indicated that BIN1 plays an essential role in minimizing inflammation and suppressing cancer. Specifically, BIN1 gene ablation enhances the rate of incidence of liver and lung carcinomas (Chang, et al., 2007a). Loss of BIN1 and activated-ras coordinate and enhance the progression of colon and breast carcinomas, supporting the fact that BIN1 limits the oncogenic potential of c-myc (Chang, et al., 2007b).

7. DISCUSSION

Various studies have shown that the tumors where IDO has been over-expressed, 1MT potentially limits the growth and progression of tumors (Friberg, et al., 2002; Uyttenhove, et al., 2003). However, due to lack of pharmacokinetic aspect of these studies, it is difficult to determine whether dosage has been inadequate to initiate the regression of developed tumors, rather than just limiting the growth. Various laboratories investigated that 1MT is stable in serum and accumulates to sufficient levels to inhibit IDO *in vivo* when dosed under circumstances that could initiate rejection of an allogenic fetus (Muller, et al., 2005a).

It has also been revealed that under same conditions, 1MT only limits the tumor outgrowth in an autochthonous mouse model of breast cancer, the MMTV-neu transgenic mouse (Muller, et al., 2005a). Hence, 1MT alone is unable to initiate tumor regression on its own, thus it shows very limited efficacy in terms of monotherapy. Alternatively by combining 1MT with any cytotoxic agent of chemotherapy such as paclitaxel, resulted in strong regressive response to established tumors in the

mouse model, where single therapy had poorly responded (Muller, et al., 2005a).

Administering subsequent dose, route and schedule of 1MT, it has been shown that a twice oral dose for just 4-5 days was plentiful to produce required tumor regression response in tumor bearing mice on trial (Hou, et al., 2007). It has also been shown that presence and targeting of IDO is essential for the action of 1MT, which was revealed by lack of 1MT antitumor activity demonstrated in IDO deficient mice (Hou, et al., 2007).

The concept that chemotherapy can be made effective by inhibiting IDO has been further supported by efficacy patterns of novel small inhibitor molecules of IDO that have been discovered recently. The continuous delivery to overcome its rapid clearance, the new inhibitor of IDO, methyl-thiohydantoin tryptophan presents greater potency but the same level of efficacy as 1MT (Muller, et al., 2005a). In addition natural inhibitors of IDO, such as brassinin, with already known cancer prevention activity in rodents (Mehta, et al., 1995), present antitumor efficacy on similar lines as 1MT (Gaspari, et al., 2006; Banerjee, et al., 2007).

Preclinical data for a potent IDO inhibitor called NLG919, has been presented at the annual meeting of American Association for Cancer Research (AACR) 2013. This data shows that NLG919 in addition to inhibition of IDO pathway *in vitro* and cell based assays, is bioavailable orally, and presents a favorable pharmacologic and toxicity profile. Indoximod (NLG8189 or D1-MT) is another inhibitor produced by the same entity is already in clinical trials, for the treatment of breast and prostate cancer. Both indoximod and NLG919 demonstrate synergic antitumor activity and T-cell activation.

So far, Indoximod has appeared to be efficient and favorable as a single agent as well as in association with docetaxel or dendritic cell vaccines. Thus, Indoximod serves as an ideal candidate to experiment other IDO novel candidates to improve the response of immune system from several other checkpoint inhibitors including PD-1/PD-L1 and CTLA-4 antibodies. By incorporating IDO inhibitors to protocols of immunotherapy, response rate to several checkpoint inhibitors can be increased. It appears that these inhibitors work best in association with immunomodulatory agents. Further determination of best combinations to use will still need some further clinical trial.

In conclusion, IDO presents a strong candidate for immunotherapy and synthetic approaches should be applied to obtain better candidates for inhibitors with lesser side effects and dose adjustment issues. Further the role of the IDO1/ IDO2 balance in cancer also warrants study to map the precise pathways of immune escape and broadening the understanding of the complex inter cellular interplay in immune evasion. The results for Clinical trials of 1-MT in glioblastoma patients of USA are highly anticipated and will open new avenues of study once data on IDO inhibition in human patients is revealed.

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MEDICINAL AND ANTIMICROBIAL PROPERTIES OF MUSHROOMS

*Zakaria Ahmed**

ABSTRACT

Medicinal mushrooms or their extracts are used or studied for possible treatments of diseases. Some mushroom constituents including polysaccharides, glycoproteins and proteoglycans, modulate immune system responses and inhibit tumor growth. In preliminary research, whereas various other species of mushrooms produce antiviral, antimicrobial, anticancer, antihyperglycemic, cardioprotective, antidiabetic properties, as well as antiparasitic and anti-inflammatory compounds.

Keywords: *Mushroom, Antimicrobial, Medicine.*

1. INTRODUCTION

Mushrooms are unique within the fungal kingdom because they produce complex fruiting body. They are saprophytes. All of the mushrooms are placed in a division Eumycota meaning 'The True Fungi'. They are divided into other groups depending on the structure of their fruiting bodies and various other macro- and microscopic characteristics. The two major groups of Eumycota are Basidiomycetes and Ascomycetes. They include members of the Basidiomycota, within the class of Homobasidiomcetae.

Mushrooms have been a food supplement in various cultures and are cultivated and eaten for their edibility and delicacy. They fall between the best vegetables and animal protein source. Mushrooms are considered as source of proteins, vitamins, fats, carbohydrates, amino acids and minerals [1]. All essential amino acids as well as water-soluble vitamins and all the essential minerals are present in it [2]. Mushrooms are good sources of vitamins like riboflavin, biotin and thiamine.

Ogundana and Fagade [3] indicated that mushroom is about 16.5 % dry matter out of which 7.4 % is crude fiber, 14.6 % is crude protein and 4.48 % is fat and oil. Protein contents vary between 4 to 9 % in Auricularia species and between 24 to 44 % in Agaricus species. The protein value of mushrooms is twice as that of asparagus and potatoes, four times as that of tomatoes and carrots, and six times as that of oranges [1]. Their energy value also varies according to species, which is nearly equal to that of an apple. In recent times, mushrooms have assumed greater importance in the diets of both rural and urban dwellers. They are also relatively much cheaper than beef, pork and chicken that contain similar nutrients. Many mushrooms have long been valued as tasty, nutritious food by different societies worldwide. Mushrooms are popular and valuable functional food, low in calories and high in minerals, essential amino acids, vitamins and fibers.

The results of proximate analysis by Adejumo and Awosanya of four edible species of mushroom collected from Nigeria [4] indicated that *Termitomyces mammiformis* was a very good source of crude protein, crude fiber, ash, calcium and manganese. *Russula vesca* was the richest in carbohydrate and magnesium, while *Lactarius triviralis* was found to be the richest in moisture content, iron and copper. It is also a good source of carbohydrate, calcium and manganese. *Lentinus tigrinus* is the richest in dry matter, and is also rich in carbohydrate, magnesium and copper. It was observed that lipids, sodium and phosphorus contents of the four species were generally very low. The results of mineral values [4] of the four edible species of mushrooms clearly indicate the potential for their use as sources of good quality food. It was observed that these four edible mushrooms hold tremendous promise in complementing the protein and mineral supply deficits prevalent in developing countries.

2. ANTIMICROBIAL PROPERTIES

Different types of mushrooms have different antimicrobial properties that are useful for human health. *Pleurotus tuber-regium* is useful in some combinations to cure headache, stomach ailments, cold and fever, asthma, smallpox and high blood pressure [5, 5a, 5b], while *Lentinus tuber-regium* and *L. tigrinus* are used for treating dysentery and blood cleansing, respectively. *Auricularia species* have been traditionally used for treating hemorrhoids and various stomach ailments [6]. *Boletus edulis* and *Lactarius* species are used for killing flies, while the puffballs are used for healing wounds [7-8]. They are also recommended to diabetic and anemic persons, owing to their low carbohydrate and high folic acid content. Some mushrooms are known for possessing anti-allergic, anticholesterol, anti-tumor and anti-cancer prorates [1].

It was observed that *Fomes lignosus* possess some curative effects against some bacterial infections and intestinal disorders [9, 5a, 5b]. Jonathan, et al, [9] also reported the antagonistic effect of extracts of some

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Nigerian higher fungi against selected pathogenic microorganisms. Olawuyi, et al., [10] reported the antibacterial activities of the distilled water, ethanolic and chloroform extracts of *Fomes lignosus* against three Gram-negative bacteria (*Escherichia coli*, *Proteus mirabilis* and *Pseudomonas aeruginosa*) and two Gram-positive bacteria (*Bacillus cereus* and *Staphylococcus aureus*) where the antibacterial activities of the tested mushroom vary and are target microbes specific. The activity of *F. lignosus* extract of chloroform and ethanol against *S. aureus* was significantly higher. According to Olawuyi, et al. [10], Gram-negative bacteria are more sensitive to fresh *F. lignosus* than *Gram-positive bacteria*.

3. MEDICINAL USES

Recently, the demand for more effective and safer therapeutic agents for the chemoprevention of human cancer has increased. Natural products produced by plants and their synthetic derivatives are expected to play an important role in the development of innovative agents to inhibit the onset of cancer [11]. Macro fungi, such as mushrooms and enthomopathogenic fungi, are good sources of natural medicines that exert antitumor activity. *Polysaccharides* are the best known and most potent mushroom-derived substances because they inhibit the growth of many types of tumors [12-13]. Natural antitumor *polysaccharides* isolated from mushrooms include, acidic and neutral compounds with different types of glycosidic linkages, as well as some that are bound to protein or peptide residues such as polysaccharide protein complexes [12-14].

Animal studies show mushrooms have anti-inflammatory activity. Inotilone, quercinol, antcin A, and benzocamphorin F, are anti-inflammatory compounds isolated from mushrooms. *Pholiota squarrosa* contains xanthine oxidase inhibitors. *Coprinopsis atramentaria* contains coprine, which metabolizes to 1-aminocyclopropanol, an inhibitor of acetaldehyde dehydrogenase. A number of mushrooms inhibit 5-α reductase and/or aromatase in vitro. In Southeast Asia, especially in China and Japan, mushrooms have long been acknowledged for their medicinal and analeptic qualities in addition to their desirable flavors and nutritional value. Several mushroom species display anti-oxidant power [15-16], and mushroom-derived polysaccharoproteins are reported to scavenge active oxygen species [17].

The medicinal properties of mushrooms have long been recognized, especially in Oriental cultures, and modern techniques have identified numerous bioactive mushroom components, which are variously reported to exhibit anti-cancer, anti-tumor, anti-viral, immunomodulatory, hypocholesterolaemic and hepatoprotective activities [6]. More recently, it has been shown that fruit bodies of *A. bisporus* and *G. lucidum* contained bioactive compounds that prevented H_2O_2-induced oxidative damage to cellular DNA (18). Although the medicinal effects of *G. lucidum* products are well documented [19], there are few reports attributing medicinal properties to *A. bisporus* even though it is the most widely cultivated and consumed edible mushroom [20]. Quinoid compounds obtained from this mushroom have been reported to suppress the propagation of mouse ascites tumor [21], and a lectin from this species also reversibly inhibited the proliferation of human colon carcinoma cells [22]. Both cellular components and secondary metabolites of a large number of mushrooms have been shown to affect the immune system of the host, and therefore could be used to treat diseases of clinical importance [5a].

It is well known that mushroom polysaccharides primarily exert their antitumor activity via activation of the immune response of the host organism (immunoenhancing activity) [23]. This indicates that mushroom polysaccharides do not directly kill tumor cells. Rather, they help the host to adapt to various biological stresses and exert a nonspecific action on the host, supporting some or all of the major systems. Because mushroom polysaccharides cause no harm and place no additional stress on the body, they are regarded as biological response modifiers. Immunoenhancing activity has been observed in many mushroom polysaccharides [24].

Ganoderma lucidum has been widely used in China and Japan for thousands of years for the treatment of various diseases, including cancers, confirming its possibility of revitalization and curing of different illnesses. It acts as antitumour, anti-inflammatory, antiviral (e.g. anti-HIV), antibacterial, antiparasitic, immunomodulating and hepatoprotective. It has a role in blood pressure regulation, against cardiovascular disorders and chronic bronchitis, like kidney tonic and nerve tonic [25a]. Pharmacologically, a number of the water-soluble polysaccharides have demonstrated antitumour and immunostimulating activities. *Karst* is one of the most often used mushrooms in traditional medicine of Far Eastern people. Because of its bitter taste and wooden built it is not suitable for nutrition, but the bioactive substances extracted from this mushroom possess very important medicinal characteristics.

Polysaccharides, β-glucans, obtained through the processes of hot water extraction, alcohol precipitation and dialyses refining had influence on the reduction of B cells (a human B cell line transformed by Epstein-Barr virus) and T cells (an immortalized line of human T lymphocyte cells). Among all tested concentrations of mushroom extract, the most intensive influence showed concentration of one mg/ml, which reduced the number of B cells by 61.46%, while in the case of T cells their number were reduced by 57.14% [26]. Edible mushrooms have beneficial effects on health and in the treatment of disease through their immunomodulatory, anti-neoplastic and lipid-reducing properties [25b, 26]. The *Shiitake* mushroom (*Lentinus edodes*), for example, has served as a model for investigating functional mushrooms and isolating pure compounds for pharmaceutical use [27]. Water extracts of the Shiitake fruiting bodies have been shown to prevent tumor growth in mice [6, 28-29]. Mushroom s polysaccharides, especially the high-molecular-weight b-Dglucan have been considered to have anti-cancer activity [30]. Iris, et al., [31] stated that *P. ostreatus* has anti-proliferative and pro-apoptotic activities where they described a newly identified low-molecular-weight ∝-glucan with promising anti-tumorigenic properties and demonstrated its direct effect on colon cancer cell proliferation via induction of programmed cell death.

A major strategy for colon cancer chemoprevention is the search for nutritional components directed at inducing apoptosis of cancer cells. Edible mushrooms have beneficial effects on health and in the treatment of disease through their immunomodulatory, anti-neoplastic, and lipid-reducing properties [32-34]. *Inonotus obliquus* has been used as a folk medicine due to its antitumor properties against several types of cancer cells [11, 35-36]. In some cases, the therapeutic efficiency of *I. obliquus* has been demonstrated clinically. For example, a decoction of fungal sclerotia did not show toxic effects and has been used in the treatment of cancers and digestive system diseases [37, 39]. Recently, in addition to polysaccharides, many polyphenolic compounds such as triterpenoids, steroids and ergosterol peroxides from *I. obliquus* have been found to possess biological activities, including antioxidant, antibacterial, hepatoprotective, platelet aggregation inhibitory and antitumor effects [35, 38, 40-47].

Sung, et al., [48] reported that the hot water extract of *Inonotus obliquus* exerts inhibitory activity against the proliferation of human colon cancer cells (HT-29) and their results suggested that this mushroom would be useful as an antitumor agent via the induction of apoptosis and inhibition of the growth of cancer cells through up-regulation of the expression of proapoptotic proteins and down-regulation of antiapoptotic proteins [48]. Mizuno reported that polysaccharides from fungal sclerotia, which are known to include hetero-polysaccharide and homoglycan, showed strong antitumor effects, while polysaccharides from cultured mycelia did not (49-50). However, Kim, et al. [51, 23] reported that the polysaccharides extracted from cultivated mycelia (termed endo-polysaccharides) also have anticancer activity. *Agaricus bisporus* extracts demonstrated immunomodulatory activities *in vivo* [52-53] and activity against several cancer cell lines [22]. *Agaricus subrufescens (Agaricus blazei/brasiliensis/sylvaticus)* is another medicinal mushroom associated with Brazil and Japan. There was an evidence for using *Agaricus subrufescens* extracts for certain cancers [54-56] whereas *Agrocybe aegerita* has anticancer activity *in vivo* [57].

Auricularia auricula extracts demonstrated hypoglycemic *in vivo* and anticancer, anticoagulant, and anticholesterol activities *in vitro* [58-59]. An Auricularia polytricha isolate inhibited sarcoma in vivo [60]. A *Boletus edulis* isolate inhibited several cancer cell lines and was found to bind a cell-specific T-antigen disaccharide [61]. A Coprinus comatus extract inhibited adenocarcinoma *in vitro* [62]. *Dictyophora indusiata* creates dictyophorines, dictyoquinazols, and tyrosinase inhibitors [63]. Epidemiological studies in Japan have associated *Flammulina velutipes* consumption with lower cancer rates [64]. Proflamin, an isolate of *Flammulina velutipes*, has anticancer activity *in vivo* [65]. *FIP-5* is an immunomodulatory protein isolated from *Flammulina velutipes*. Many *Grifola frondosa* studies indicate potential anticancer and antihyperglycemic activities. Antiatherosclerotic, antifungal and immunomodulatory compounds have been isolated from *Hypsizygus tessellatus*.

Lentinan is an isolate of *Lentinula edodes* mycelia. In Japan and China, lentinan is an adjuvant for gastric cancer [66]. AHCC is an extract derived from fermented *Lentinula edodes* mycelia. The *Lentinula edodes* isolate eritadenine, is an inhibitor of S-adenosyl-L-homocysteine hydrolase, and has hypocholesterolemic activity. *Lignosus rhinocerus* is a medicinal mushroom associated with Malaysia [67]. A *Morchella* esculenta isolate demonstrated immunomodulatory activity *in vitro* [68]. *Phallus impudicus* extracts have been clinically researched in

relation to venous thrombosis [69]. *Pholiota nameko* creates compounds with antiinflammatory, immunomodulatory, and hypolipidemic activities [70-72]. A *Pleurotus djamor* isolate demonstrated anticancer activity *in vitro* [73]. *Pleurotus eryngii* extracts have immunomodulatory activities *in vitro* [Nozaki, et al. 2008].

A number of studies indicate *Pleurotus ostreatus* consumption lowers cholesterol levels *in vivo*. Research with *Pleurotus ostreatus* extracts indicates potential anticancer and immunomodulatory activities [34, 74-75]. *Sparassis crispa* has anticancer and immunomodulating activity *in vivo* [76-77a,b, 78-79]. A *Tremella fuciformis* isolate protected against effects of radiation in vivo. *Tremella mesenterica* has potential anticancer and immunomodulating activities [80a, 80b, 81]. *Tricholoma matsutake* isolates may have anticancer and immunomodulating activities [82-88]. *Volvariella volvacea*, a mushroom associated with Thailand and Vietnam, has anticancer activity in vitro [73].

4. CONCLUSION

It has been known for many years that selected mushrooms of higher Basidiomycetes origin are effective against cancer. There are approximately 650 species of higher Basidiomycetes that have been found to possess antitumor activity. Searching for new antitumor and other medicinal substances from mushrooms and studying the medicinal value of these mushrooms has become a matter of great significance. Some countries classify mushroom isolates as antineoplastic compounds. Mushrooms and other forms of fungi create antimicrobial and antiviral compounds. Now-a-days consumption of medicinal mushrooms is increasing strongly. Therefore, this review gives room for improvement of technological knowledge in the determination of antimicrobial and medicinal substances from selected mushrooms, which will be useful in production of valuable antibiotic drugs in pharmaceutical industries.

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RAINWATER HARVESTING POTENTIAL SITES AT MARGALLA HILLS NATIONAL PARK

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ABSTRACT

Life without water is not possible. Adoption of modern lifestyle and increase in population is leading to a water scarce world. The demand of world population cannot be met with the scarce surface water, which is resulting in increased groundwater abstraction. The world is facing water crisis and Pakistan is no exception. Urban areas of Pakistan are affected badly where extraction is higher while the construction of pavements has disturbed groundwater infiltration. The Federal Capital of Pakistan, Islamabad, is located in Pothohar region of the country and faces severe water shortages, particularly during summers. Extensive drilling by public and private users lowers groundwater table. Satellite imagery of LANDSAT 7 ETM+ and ASTER DEM 30m resolution were used to construct the site suitability map for groundwater recharge of Margalla Hills National Park. Factors considered included land cover, drainage density, elevation and slope. Suitable weightages were assigned to these factors according to their influence on infiltration in the study area. Groundwater recharge at Margalla Hills National Park will be effective in dealing with water crisis in Islamabad as it will raise groundwater table of the adjacent areas.

Keywords: *Water scarcity, Groundwater recharge, Margalla hills, Islamabad, Urban sectors*

1. INTRODUCTION

Water is a vital natural resource. Humans as well as other living things depend on water as the basic need of their lives. Demand for this precious resource is increasing in every part of the world. Water is used in domestic, agricultural and industrial sectors. Rapidly growing world population combined with modern lifestyle, hasty urbanization and industrialization has drastically raised the demand for water and is resulting in a water scarce world [2].

Quality and quantity of surface water is affected due to anthropogenic activities. To meet the increased demand for water, pressure on groundwater is amplifying [6]. Groundwater abstraction is boosting for three major kinds of reasons: technological, hydrological and policy. Technological advancements have provided people with cost-effective and easy means to access water from tube wells through efficient mechanical pumps. Such affordable technologies have increased dependence on groundwater while providing short-term benefits to users. But in the long run, it is causing groundwater depletion [5]. Apart from this technological factor, another significant factor is water scarcity where surface water fails in meeting water needs and people are compelled to use groundwater. On the other hand, some of the government policies also encourage groundwater abstraction by providing loans and subsidies for pumping water from tube-wells [8].

Groundwater is a precious resource, and its tactical significance can be understood by considering the explicit data, which indicates that 25 % of global irrigation is dependent on groundwater, while in arid and semi arid regions this dependence reaches 60 % for agricultural use only [10-14]. About 80 % of the groundwater extraction is carried out in some of the most populated countries of the world, which include China, India, Bangladesh, Pakistan and the United States [4,9]. There is an inverse relation between water resource and population growth. Pakistan is a developing country with rapidly growing population, while its water resource is depleting at the same rate [3]. Groundwater resource is not protected under any legislation in Pakistan. Any person having land and sufficient financial resources can install a tube-well on the land and extract any amount of water at any given time without consideration of safe yields. Groundwater abstraction in 1965 was 10 billion cubic meters (BCM) and in 2002 it reached 68 BCM. Private users are the major exploiters of groundwater, and are involved in about 80 % of its abstraction [7].

Insufficient piped water and reduction in monsoon rains have increased dependence on groundwater. Abstraction of water for non-drinking purposes decreases groundwater level [6,9]. Urban areas are more adversely affected. Water-table statistics of Islamabad show that there has been a 50 feet drop in the water-table from 1986 to 2001 [2]. Reservoirs fall short in meeting the demands of the Federal Capital. A decade ago, groundwater was found at 50-100 feet depth and now it is way after 250-300 feet of drilling [12].

Statistics of Capital Development Authority (CDA) of the Federal Capital show alarming trend as 10 tube wells dried up recently and rate of depletion is even faster. Groundwater recharge is a natural process but urbanization and anthropogenic activities affect this process. Therefore, artificial recharge processes are becoming popular at global level [1]. According to the

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Table-1: Number of Tube Wells in Different Sectors of Islamabad

Sectors of the City	No. of Tube-wells
I and H Sectors	54
F and G Sectors	67
NPAs series	67
Total	**188**

Table-2: Statistics Showing Tube Wells Water Production in Islamabad

Tubewells Water Production (MGD)	
Design Capacity	36
Production Capacity	29
Actual Capacity	17

CDA statistics, there are a total of 188 public tube-wells supplying water to the capital city apart from private tube wells being installed by the city residents. Despite a large number of tube wells in the city, the gap between actual capacity and production capacity of the tube wells is quite noticeable, as shown in Table-1 and Table-2.

This problem of groundwater depletion could be tackled to a certain extent by artificially recharging the potential aquifers. In areas of hard-rock terrains, groundwater availability is limited to fractured and weathered soil horizons. Efficient planning and management of such areas is of top priority concern [7].

Water resource management is one of the major concerns of policy makers. Rainwater harvesting (RWH) can give significant results for recharging both surface as well as groundwater. RWH is basically to store rainwater for future use; it helps in increasing groundwater table. RWH systems are important in managing scarce rainfall, and success of these systems mainly depends on identification of suitable potential sites and technologies [6,15].

CDA is implementing a pilot project for use of rainwater to recharge groundwater, which can lead to wide spread use in management of groundwater in urban areas of the country. Pilot project of CDA makes Islamabad the first city in the country to establish RWH system. It is expected to play a significant role in water-table recharge. First RWH structure was established at the site of Faisal Mosque and following the success of this project, CDA further identified 20 more potential sites in the city for rainwater harvesting.

Site identification for RWH depends on various factors, applying conventional methods for this task takes long time and there are many chances of oversight. Advanced and efficient techniques like remote sensing (RS) and geographic information system (GIS) are giving momentous results. Generation of thematic maps by the use of Remote Sensing and its integration with GIS can be useful in identifying potential rainwater harvesting sites. The process of decision making in rainwater harvesting can be effectively carried out by using this technique. Margalla Hills are very important from the groundwater recharge point of view as it is responsible for recharging Nullah Lai basin and the Rawal sub-watershed that nourishes Rawal Dam and provides water for both domestic and agricultural use for residents of Islamabad.

2. METHODOLOGY

Methods and materials used to conduct the study were based on:

- Landsat7 ETM+ image of year 2005;
- ASTER digital elevation model (DEM) of 30 meter resolution;
- Similarly a geological map of the Islamabad region on the scale of 1:150,000.

The satellite imagery and ASTER DEM was acquired from U.S. Geological Survey (USGS) website and the geological map was obtained from Geological Survey of Pakistan.

Software used in this study were:

- ERDAS IMAGINE 2013
- ARCGIS 10

Supervised classification was applied on LANDSAT 7 imagery for obtaining the land cover map of the area.

Table-3: Weights and Scores of Different Factors Affecting Directly or Indirectly the Water Recharge

Factors	Score	Maximum Weightage
Land use		
Vegetation	5	**15**
Water body	4	
Scrub land	4	
Built area	1	
Barren land	3	
Drainage density		
0-1.18	5	**15**
1.18-1.99	4	
1.99-2.76	3	
2.76-3.61	2	
3.61-5.39	1	
Elevation		
460-650	5	**20**
650-811	4	
811-989	3	
989-1193	2	
1193-1598	1	
Slope		
0-7	5	**20**
7-15	4	
15-24	3	
24-34	2	
>34	1	

Source: *[Ref. 10-14]*

Furthermore, Raster Attribute Table was used to calculate area of different parts of the map. The processing of ASTER DEM in Arc GIS helped in the generation of maps for different factors controlling the groundwater infiltration (i-e, drainage density, slope, and elevation). Geological map was found to be helpful in finding different soil types in the study area.

3. RESULTS AND DISCUSSION

Geological studies show that areas lying at the foothill of Margalla Hills are generally covered by alluvium, which consists of surficial deposits of mainly clay with sand and semi-consolidated gravels with average thickness between 5-20 m [13].

Five classes were identified: forest, scrub land, water body, barren land and urban land, where forest cover was found to cover maximum area (i.e., 39 % of the total area). Since land cover plays a significant role in groundwater infiltration, therefore, the overall weight given to this factor was 15.

The elevation of study area ranges between 495 m to1,598 m. On the other hand, about 70 % of the area was recorded to have gentle to moderate slopes, which favors the water infiltration. As in relation to groundwater infiltration, the flat/level and gentle slopes hold more rainfall, which is the primary source of groundwater recharge since level and gentle slopes allow more time for water to infiltrate [14]. Similarly the drainage network observed in the study area follows dendritic pattern, which is the characteristic of areas with moderate slope while it changed into parallel drainage network pattern at much higher sloppy area.

Suitable weightages were assigned to different factors in the study area, since these factors (slope, elevation, drainage density, and land use) control the water flow and directly or indirectly influences the water infiltration into the ground as are shown in Table-3.

For identifying such zones, the weighted overlay analysis of the above mentioned layers was done by using 1 by 3 by 1 scale. The resultant layer was then classified into 3 classes based upon suitability scale, i.e., least suitable, slightly suitable and highly suitable as shown in Figure-1.

The importance of groundwater recharge in the Margalla Hills can be understood through the effect it will have on the water-table situation of the areas lying

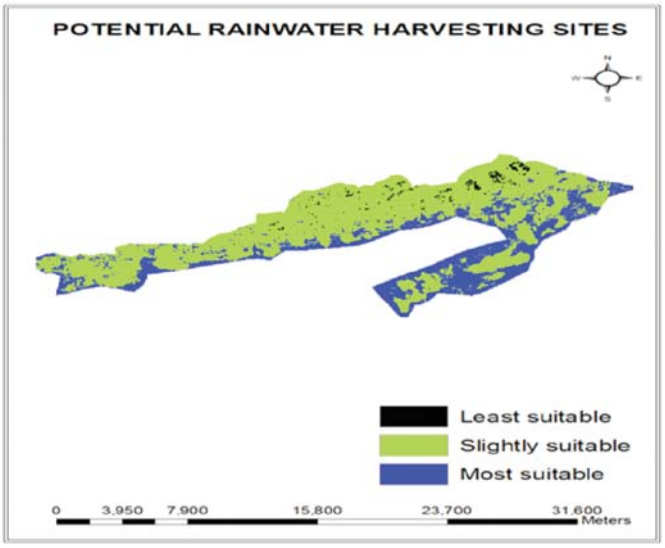

Figure-1: Map Showing Potential Suitable RWH Sites at Margalla Hills National Park

at its foothills. Since streams originating from these hills are the main source of groundwater recharge for the areas lying at foothills and also are a source of surface water for the residents of capital city, as all the streams ultimately drain into Rawal Lake. The water recharge at Margalla Hills will help in raising the water-table level of the surrounding areas through increasing stream water flow, and the resultant increased runoff could be utilized effectively through harnessing of runoff by installing water harvesting structures at areas which are worst hit by climate change, like I-8, I-9, I-10, G-7, G-8, G-10 and G-11 sectors of Islamabad.

4. CONCLUSIONS

In this water scarce world, trend towards groundwater recharge is increasing rapidly. Suitability of groundwater recharge site is dependent on various factors and conventional methods cannot give significant results. This study was based on time and cost effective methods of remote sensing and GIS. The study was based at Margalla Hills national park and focused on many factors like land cover, drainage, elevation, slope, aspect and rainfall. Combined results of satellite image classification and GIS analysis of ASTER DEM produced final site suitability map for groundwater recharge in the study area. Areas on the map were categorized as suitable, slightly suitable and highly suitable, depending upon their suitability for recharge. Installation of recharge structures at suitable sites will increase the level of water-table and reduce the threat of water shortage during the coming years. Following similar approaches for other parts of the country will help in managing water crisis at national scale.

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ENERGY PRODUCTION FROM WASTE-WATER USING MICROBIAL FUEL CELLS

Syed Hasnain Shah[†] and Iftikhar A. Raja**

ABSTRACT

Natural energy sources like fossil fuels are depleting due to increased human activities. Different types of alternatives are being explored to solve this problem with the consideration that they are sustainable. There are many environmental concerns connected with fossil fuel burning, which after oxidation processes release greater amounts of carbon emissions in atmosphere. Now the trends are shifting towards exploiting renewable energy options, such as bioethanol, biodiesel, biohydrogen, biogas, and bioelectricity. Bioelectricity is harvested from organic substrates using Microbial Fuel Cells (MFC) that operate on oxidation reduction (redox) reactions. MFCs produce electricity in the presence of microorganisms from biodegradable substances. Waste-water contains enormous amount of organic matter that can be oxidized in MFC for electricity harvesting. In this review, the main focus is made on the applicability of microbial fuels cells for simultaneous waste-water treatment and electricity production.

Keywords: *Microbial Fuel Cell, bacteria, power, electricity, waste-water*

1. INTRODUCTION

Renewable energy is the need of the hour. Efforts in the developed world are being made to explore the alternative options of renewable energy resources that do not further exacerbate the carbon foot-prints. The exploitation of microorganisms for the production of electrical energy through Microbial Fuel Cells (MFC) is considered to be one of the most effective options [1]. MFCs are the types of fuel cells that convert chemical energy present in the molecules of organic substrates into electrical energy by oxidizing the biodegradable substrates using biocatalysts, such as bacteria. MFC has become the best solution for wastewater treatment and energy production at domestic level because of the fact that bacteria can oxidize the substrates into electricity [2]. MFC technology is now taking a significant position as a source of bioenergy production. Therefore, its applicability at domestic level has been studied extensively. Bruce Logan reported that MFCs can generate electrical power as much as 1kW/m^3 of biological reactor volume [3]. This paper focuses on the technology, technical challenges and future perspectives in using MFC.

An MFC is basically made up of two electrolytic chambers, i.e., anodic and cathodic chambers that are kept separated using proton exchange membrane (PEM), along with an external circuit (Figure-1). In the anode compartment of MFC, bacterial community is present that through bio-electrochemical system consume organic substrates (organic matter in wastewater) as a fuels source to produce electrons and protons [4]. The electrons generated in this process are accepted in the electron-transport chain by nicotinamide adenine dinucleotide (NADH), and subsequently transferred to terminal electron acceptors, such as nitrate, sulphate and oxygen [5]. These electrons are then transferred to anode through bacteria from where they reach the cathode via an external electrical circuit, thus electric current is produced. In external circuit, the presences of suitable resistance is required. The potential difference and electrical current production are estimated by means of a voltmeter or ammeter, respectively, connected to the device [6].

Protons are generated during oxidation process in cathode chamber, which are then transported or diffused by means of proton exchange membrane (PEM). Protons subsequently combine with the electrons and oxygen to form water at the cathode in the cathodic chamber. Anaerobic conditions are maintained in the anode, compartment because oxygen inhibits electricity generation. In cathode compartment oxygen is supplied which act as an electron acceptor [7]. At anode biodegradation takes place where organic matter is biochemically oxidized and as a result carbon dioxide is liberated, and the resulted protons are diffused to cathodic chambers. Electrical current is produced when electrons are brought to flow in circuit. To maintain this current an external resistance is required [8].

2. ENERGY FROM WASTEWATER THROUGH MFC

It has now become a universal truth that energy is the currency, which will drive the global economy in the future. According to the estimation made by Lewis, energy consumed by humans in terms of the number of joules in a typical year and dividing them by the number of seconds in a year results in an average burn rate of about 13 trillion watts (13 TW) [9]. This is the amount of power which is consumed all around the world to maintain energy balance of human activities. The economic activities are directly and indirectly

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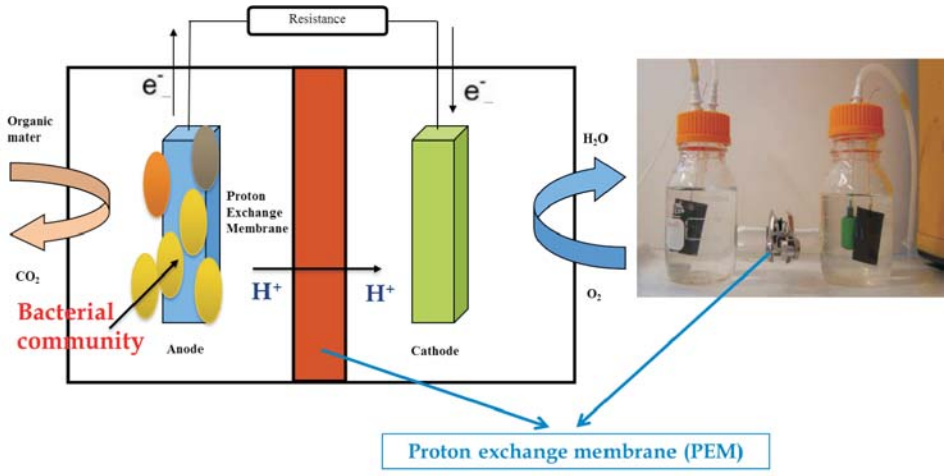

Figure-1: Graphical Representation of Microbial Fuel Cells [Ref. 27]

affected by the energy supply. Without compromising the needs of developing world, an enormous increase in energy supply is required to encounter the challenges and demands of the overall growing world population and to reduce poverty.

In order to harvest electrical energy from organic matter, MFCs are expected to provide a bio-electrochemical power option. MFC can also utilize the waste-water as a source of organic substrate to remove contaminants and simultaneously produce electricity. This can also reduce the operational budget of the waste-water treatment.

Chemical reaction:
MFCs have received more attention in the recent

$$\text{Wastewater} + H_2O \rightarrow nH^+ + yCO_2 + ne^-$$
$$\tfrac{1}{2}\,O_2 + 2H^+ + 2e^- \rightarrow H_2O$$
$$\text{Wastewater} + O_2 \rightarrow 2H_2O + CO_2$$

years. Wide range of studies were conducted on different biodegradable organics substrates in waste-water, such as glucose, acetate, sucrose, domestic waste-water, brewery waste-water and waste-water containing starch from pulp and paper industries. But there are only a few reports published on *bio-refractory compounds*, i.e., for instance fuels, furfural, phenol, pyridine, and *p*-nitrophenol, etc. These reports indicate that if the MFC technology is used in practical applications, organic material in the waste-water might be suitable resource for electricity generation [10].

3. ELECTRON TRANSFER MECHANISMS

In MFCs, there are mainly two ways by which the electrons are transferred from bacterial culture in anodic chamber to electrodes. It may be of either direct transfer (mediatorless) or indirect electron transfer (mediator MFC) [11].

3.1 Direct Electron Transfer

There are several microorganisms that can transfer electrons from inside the cell to extracellular acceptors through c-type cytochromes, biofilms and highly conductive pili (nano-wires or nano-tubes), i.e., *Shewanella putrefaciens*, *Geobacter sulferreducens, G. metallireducens* and *Rhodoferax ferrireducens* (Figure-2). These microorganisms possess high Coloumbic efficiency and can result biofilms formation on the anode surface, which then act as electron acceptors and shift electrons directly to the anode, after which more energy is harvested [12].

3.2 Electron Transfer by Own /Artificial Mediators

In this type of electron transfer, the electrons from microbial carriers are shifted to the electrode (anode) either by a microorganisms (i.e. *Shewanella oneidensis*, or *Geothrix ferementans*) or through their own mediators or sometimes by adding mediators, which in turn result in the extracellular electron transfer.

The MFCs that operate on mediators for electron transfer are called mediator-MFCs. Mediators offer a platform for the microorganisms to generate electrochemically active reduced-products. Cell

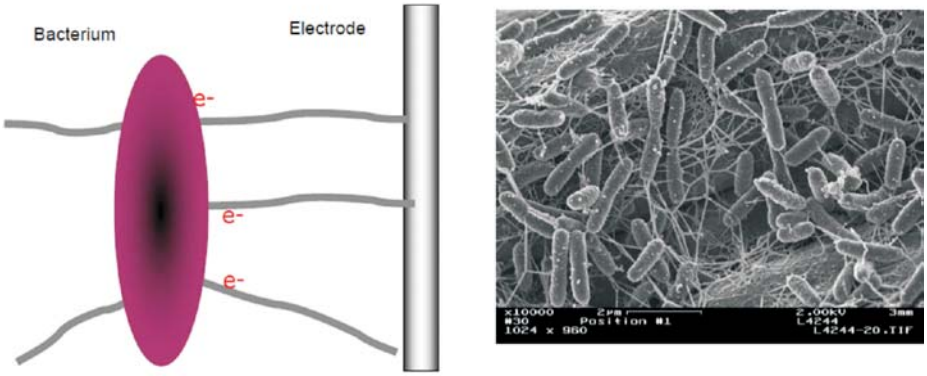

Figure-2: Bacteria Use Nanowires that can T ransfer Electrons Directly to the Electrode [Ref. 28]

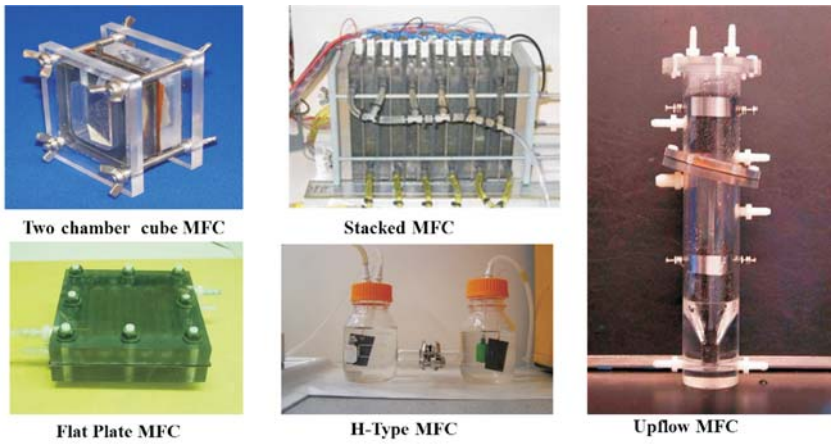

Figure-3: Different Types of Microbial Fuel Cells [Ref. 27]

Permeable is the reduced form of the mediators that can accept electrons from the electron carrier and transfer them to the surface of electrode [13]. Usually the chemicals like neutral red, methylene blue, thionine, 6-disulfonate, anthraquinone-2, phenazines and iron chelates are added to the MFCs as redox mediators [14]. MFCs that contain bacteria like *Proteus vulgaris*, *Escherichia coli*, *Streptococcus lactis*, and *Pseudomonas* require mediators because these bacteria cannot transfer electrons outside the cell. For effective working, the mediator must be able to penetrate easily in the cell membranes to grip the electrons from the electron carriers of the electron-transport chains. These should increase the electron transfer from the metabolites during long periods of redox cycling and must be non-toxic to the microbial community [15].

4. MFC DESIGNS

All MFCs have same operating principle but due to different substrates and power options, they have different modifications in their shapes (Figure-3). Using a diversity of materials, different configurations of MFCs are being established. To enhance performance, they are used under different conditions to get more power output and to reduce the overall cost [16]. There are different kinds of MFCs that are usually exploited in scientific research projects, such as:

Two chamber MFC: This is the most widely and commonly applicable and acceptable design, which consists of two chambers with the anode and cathode compartments separated by a proton-exchange membrane (PEM). The anode chamber is supplied with anaerobic environment consisting of diverse anaerobic microbial

communities depending on the substrate selectivity. This design is generally applied in basic research. Literature proposes that the power output from these systems are usually low due to their high internal resistance, complex design and electrode based electron losses [5, 17].

Single chamber MFC: This design has only one chamber that contains both the anode and the cathode inside the compartment. Variably the anode is either placed close or away from the cathode, which are separated by PEM. It has been reported that after combining, the two chambers can increase the power density because if the anode is closer to the cathode, it will decrease the internal ohmic resistance by escaping the use of catholyte [18]. As compared to the two chamber MFC, it appears to be simple, cost effective and produces more power in more efficient manners [18]. However, there are a few major drawbacks in single chamber MFC, i.e., the membrane-less configuration, microbial contamination and backward diffusion of oxygen from cathode to anode with no presence of PEM [19].

Up-flow MFC: These are cylinder shaped MFCs which comprise of anode at the bottom and the cathode at the top of the container and both electrodes are separated from each other by glass wool or with layers of glass beads. The substrate is supplied from the bottom of the anode chamber, whereas the upper cathodic chamber at the top is supplied with oxygen. For proper operation of the MFCs the diffusion barrier between the electrodes provides a gradient. It is suitable for waste-water treatment because there is no physical separation as such and no problems for proton transfer in this design. However, some times the mixing of anolyte and catholyte tends to be a major drawback of this design [20].

Stacked MFC: In this design to achieve high current outputs, many single-celled MFCs are connected to each other in series or in parallel combinations. Parallel connection can generate more energy as compared with series connection due to higher electrochemical reaction rate. Parallel connections are more subjected towards the higher short circuiting when operated at the same volumetric flow, as compared to a series connection. But there are more problems of internal resistance in it because of the involvement of increased volume of microbes and zeta-potential [21].

5. ELECTRODE MATERIALS IN MFC

The performance of MFC is affected by the choice of electrode materials. Different materials have been tested as electrodes to enhance the performance and increased power outputs from MFCs. To make anode, different materials have been investigated, i.e., carbon felt, carbon cloth, carbon mesh, graphite felt and graphite fiber brush are frequently employed due to their stable nature, high electrical conductance and large surface area [5]. For making cathodes, materials like platinum (Pt), platinum black, graphite based cathodes, activated carbon (AC), and bio-cathodes have been used [22]. Though platinum coated electrodes are not cost-effective, they are more efficient and superior in power production due to higher catalytic activity with oxygen as compared with other electrodes. Different compounds have been used instead of platinum as an alternative catalysts, i.e., manganese oxides, ferric iron, iron and cobalt based compounds. Ferricyanide ($K_3(Fe(CN)_6$) is often

Table-1: Microbial Community Analysis [Ref. 27]

Inoculum	Community	Reference
River sediment (glucose+glutamic acid)	α-Proteobacteria (mainly Actinobacteria)	Phung, et al. (2004)
River sediment (river water)	β-Proteobacteria (related to Leptothrix spp.)	Phung, et al. (2004)
Marine sediment (cysteine)	γ-Proteobacteria, 40% Shewanella affinis KMM, then Vibrio spp. and Pseudoalteromonas sp.	Logan, et al. (2006)
Waste-water (starch)	36%=unidentified, 25%=β- and 20%=α-Proteobacteria, and 19%= Cytophaga+Flexibacter+Bacterioides	Kim, et al. (2004)
Waste-water (acetate)	24%=α-, 7%=β-, 21%=γ- , 21%= δ-Proteobacteria; 27%=others	Lee, et al. (2003)

Table-2: Different Substrates with their Power Production Potentials [Ref. 27]

Substrate	Power production (mW/m^2)
Glucose	494
Acetate	506
Butyrate	309
Protein	269
Domestic wastewater	146

employed as an electron acceptor in the MFC due to its low over-potential and good performance. Bio-cathodes increase the power productions by reducing the over-potential [23]. Alternatively, the bio-cathode can contain oxygen and therefore it is given priority, due to increased cell operation and it is more commonly applied as electron acceptor in MFC.

5.1 Proton Exchange Membrane

The proton transfer from anode to cathode affects the power outputs. As the transfer of protons from anolyte to catholyte is a slow process that can result in high internal resistance. In most of the designs, MFCs need a salt bridge or PEM to separate the anode and cathode chambers. The PEM is commonly made up of polymers like Ultrex and Nafion. Although membrane-less, single chamber MFCs are reported to produce higher power density, membrane absence would increase oxygen to the anode and thus lower the coulombic efficiency and bioelectrocatalytic activity of the microbes [20].

5.2 Microbes in MFC

A wide range of bacteria have the ability to oxidize organic matter and transfer electrons to the anode along with the production of protons and carbon dioxide. In MFC, both the mixed cultures and pure bacterial cultures can be utilized [24]. It was reported that the mixed cultures have higher performance rate and more resistance towards process disturbances.

The electrochemically active bacteria in MFCs may be aerobes or facultative anaerobes, and the reaction temperature in MFCs depends on the bacterial tolerance to temperature (mesophilic/thermophilic) [25]. Not only the electrochemically active, iron-reducing bacteria (*Shewanella* and *Geobacter*), but also other group of bacteria (*Klebsiella pneumonia, Rhodopseudomonas palustris, Dessulfobulbus propionicus*) that are isolated from the waste-water showed great potential to be used in MFCs [26].

5.3 Substrate in MFC

Substrate provides not only energy for the bacterial cells to grow in the MFCs, but also influences the economic viability and overall performance, such as power density and columbic efficiency of MFCs. The composition, concentration and type of the substrate also affect the microbial community and power production. Many organic substrates including carbohydrates, proteins, volatile acids, cellulose and wastewater have been used as feed in MFC studies. It can range from simple, pure, low molecular sugars to complex organic matter containing waste-water to generate electricity. In most of the MFCs, acetate is commonly used as a substrate due to its inertness towards alternative microbial conversions (fermentation and methanogenesis) that lead to high coulumbic efficiency and power output [26]. Power generated with acetate is found to be higher, when compared with other substrates.

6. CONCLUSION

Energy harvesting from waste-water using microbial fuel cells (MFC) appears to be an attractive option for sustainable energy. The major advantages are treatment of waste-water by reducing biological oxygen demand (BOD) and chemical oxygen demand (COD). From the perspective of electric current and power production, applicability of MFCs has expanded the use of novel materials, and new cell designs are being studied for waste-water treatment. MFCs with modified treatment technologies seem to be more realistic, cost-effective and feasible for waste-water treatment. MFCs can be more realistic option for waste-water treatment as they oxidize organic matter, thus reducing pollution load in wastewater. Subsequently, through electrogenic process, electrons are generated that travel through external circuit and produce electrical power at the same time. In future perspective, MFCs are suitable option to overcome the waste-water problems and energy crises.

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TREATMENT OF ORGANIC SOLID WASTE FOR REUSE: A STEP TOWARDS ZERO WASTE

Mohsin Ali†, Zahid Mahmood Khan*, Jehangir Sial, M. H. Mahmood*, H. Shahid Rafiq*, Musharib Khan*, Imran Ali* and Iftikhar A. Raja***

ABSTRACT

Large amounts of organic solid wastes are being generated from municipal, industrial and agricultural activities. After necessary processing, the organic solid waste can be reused for agriculture not only as a nutrient supplement for plant growth, but also as a conditioner for seedbed soil. Processed organic wastes may improve soil structure and enhance water and nutrient-holding capacity of the soil, as well as increase the microbial activity within the soil, thereby increasing soil fertility. In this study, problems like undesirably high moisture contents and large volumes per unit weight of the processed organic solid wastes have been addressed through pelletization. Physical properties like durability, percent of fines content, and bulk and particle density of the processed and pelletized organic waste have been investigated, and the optimum values for storage, handling and transportation of the pelletized organic waste have been determined. Three different sizes of extruding sieve (4.35, 6.35 and 7.9 mm) and three different waste-mixing ratios (1:1:2, 1:2:2 and 1:3:3) of farmyard waste, wastewater sludge and sugar industry press mud were used respectively for the production of bio-solid pellets. The physical properties of the palletes show that durability increases by increasing the amount of sewage sludge while fines content, bulk density and unit density decrease. The large sieve size has more durability and less fine content. The results showed that the pelletization technique can be efficiently used by the farmers and appears to be a good option for sustainable management and re-use of organic solid wastes.

Keywords: *Farmyard Manure, Sewage Sludge, Pellets, Sieve Size, Durability*

1. INTRODUCTION

Today, the management and proper disposal of huge amount of solid wastes is a serious challenge faced by Pakistan. As the potential of the solid waste reuse goes untapped, inappropriate dumping practices of solid waste not only pose threat to local environment but also lead to wastage of resource. The organic component of solid waste contains sufficient amounts of nutrients that can be used as biological fertilizer. In the last few decades, Pakistan, however, has shifted to intensive agriculture, whereby excessive synthetic chemical fertilizers are used that are environmentally unsafe [1]. While on the other hand, organic wastes have the potential to be used not only as a source of nutrient supply but also as soil conditioners to improve the characteristics of the soil. Organic wastes improve the soil structure and enhance the water and nutrient-holding capacity of the soil. It also increases the microbial activity within the soil thereby increasing the soil fertility [2-5].

Slurry originating from the municipal wastewater treatment plant as a byproduct is known as sludge, and biosolids if stabilized [6-7]. The most common way to treat sludge is composting [8]. Use of industrial wastes, such as sugar-press mud, is gaining attention because of their rich nutrient content. Sugar-press mud provides sufficient supply of organic matter, major nutrients and some main micronutrients. It is recognized for its physical properties and significance in enhancing crop production and soil fertility [9]. Farmyard manure is also a valuable organic waste that has been traditionally used as a soil conditioner in agricultural fields [10].

This paper is based on an investigation that aimed at determining the optimum mixing proportion of these wastes and their physical properties for safe and more productive reuse of organic solid wastes (sewage sludge, sugar-press mud, farmyard manure) in agriculture through pelletization.

2. MATERIALS AND METHODS

The organic solid wastes used in this study included sugar-press mud, sewage sludge and farmyard manure. These wastes usually contain some portion of inorganic solids, like dust particles, sand, silt and small pebbles, which cause abrasion and blocking problems during pelletization process. Removal of such impurities is important and which was achieved through mechanical vibrating sieve of pelleting machine having 10 mm opening size (Figure-1). After separation, the material was conveyed to the hammer mill, where it was grinded in fine powder like form.

After grinding, all waste materials were mixed up manually in required proportions. Mixing ratio among the wastes (farmyard manure, wastewater sludge and sugar-press mud) were: 25:25:50, 20:40:40 and 14:43:43, respectively. Aerobic composting of these mixed wastes was done for four weeks to render it environmentally safe and agronomically more productive. Moisture was maintained in the range of 40-60 %.

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Description of Pelleting Unit

1 Waste sump
2 Bucket elevator
3 Screening chute
4 Vibrating sieve
5 Grinding mill
6 Mixer chute
7 Mixer hopper
8 Mixer
9 Extruder
10 Dryer drum
11 Burner
12 Conveyer

Figure-1: Pelleting Machine

Composted material was homogenized in the mixer assembly. During mixing, appropriate amount of water was added to increase the binding property of the material. The homogenized material then found its way into the extruder via the hopper, where the material was transformed into pellets by extruding it through the sieves of required size. These soaked pellets were then subjected to a dryer drum, where hot burnt gas was passed into a rotating drum. To achieve the class-A pellets with desired moisture and hardness, they were dried at a temperature range of 70 to 80°C for a time period of 65 to 75 seconds, which is recommended by US-EPA [11]. The treated pellets were then moved into a collecting hopper, which is the inflow point of the conveyer carrying a final product for stockpiling. The pellets were stacked up in the plant vicinity where natural curing took place. The pellets were then ready to be bagged and transported to commercial markets.

3. PHYSICAL CHARACTERISTICS OF PELLETS

i. Bulk Density

Bulk density of pellets was determined according to the ASABE Standard method S269.4 [12]. Pellets were transferred into a cylindrical container up to the top level. The extra material was removed and weight of the pellets was calculated by deducting the weight of empty container from the collective weight of pellets and container. Bulk density was calculated by dividing the mass by the container volume.

$$\rho b = M/V \quad \text{... Eqn. (1)}$$

Where:
ρb = Bulk Density of pellets (kg/m^3),
M = Mass of pellets in container (kg), and
V = Volume of container (m^3).

ii. Unit Density

Unit density of the pellets was determined by calculating the weight and volume of a few pellets individually. The volume of each pellet was determined by using the following formula:

$$V_t = \pi /4D^2L \quad \text{... Eqn. (2)}$$

Particle or unit density was calculated by:

$$\rho U = M_t/V_t \quad \text{... Eqn. (3)}$$

Where:
ρU = Bulk Density of pellets (g/cm^3),
M_t = Total mass of individual pellets (g), and

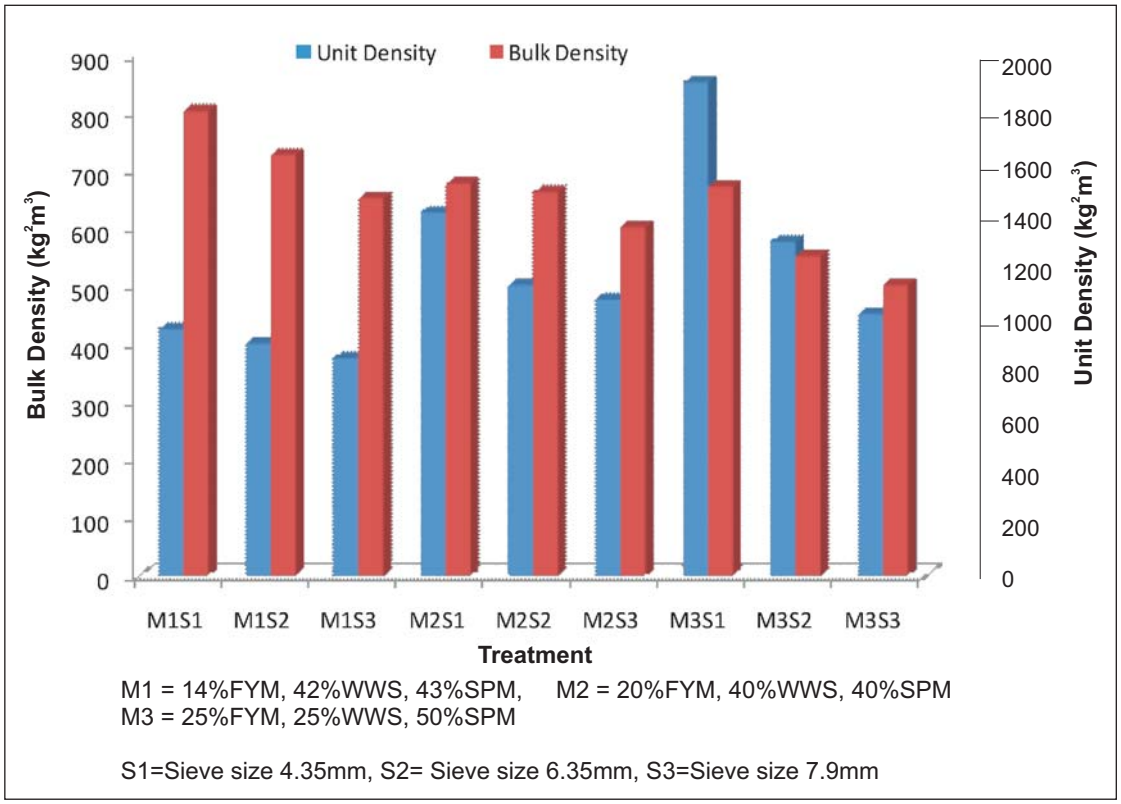

Figure-2: Relation of Mixing Ratio and Sieve Size on Bulk and Unit Density of Ppellets

V_t = Total volume of pellets (cm^3).

iii. Fines Content

Fines content means the formation of fine particles during pellet manufacturing. This is due to factors like temperature of sieve or amount of moisture present in material and the cohesive force in material [16]. Fines content was determined by the method described by Lui, et al. [13], using a 3.15 mm sieve. Pellet sample weighing 300 gms were taken and each sample was placed on a vibrating sieve for 30 seconds. The final mass was weighted again.

Fines content was calculated using the following formula:

$$P_f = (m_i\ m_f)/m_i * 100\% \quad \text{... Eqn. (4)}$$

Where:
P_f = Fines of sample (%),
m_i = Initial weight of sample (g) and
m_f = Final weight of sample (g).

iv. Durability

Durability was determined by the drop-testing method given by Oveisi, et al. [14]. A sample mass of 300 g of pellets filled in a 250x300 mm fabric bag having a zip lock on its one side was used. Before each test, pellets were sieved mechanically by using sieve analysis apparatus with 3.15 mm sieve size to separate the broken pellets. After the separation of broken pieces, pellets were put in the bag. The loosely filled bag was dropped from a height of 8 m building onto a marble floor. The pellets were once again passed through a 3.15 mm sieve and the unbroken pellets were weighed [14]. Percent breakage was determined using the following formula:

$$D = M_f/M_i * 100 \quad \text{... Eqn. (5)}$$

Where:
D = Durability (%),
M_i = Initial mass of pellets before drop (g),
M_f = Final mass of pellets after drop (g).

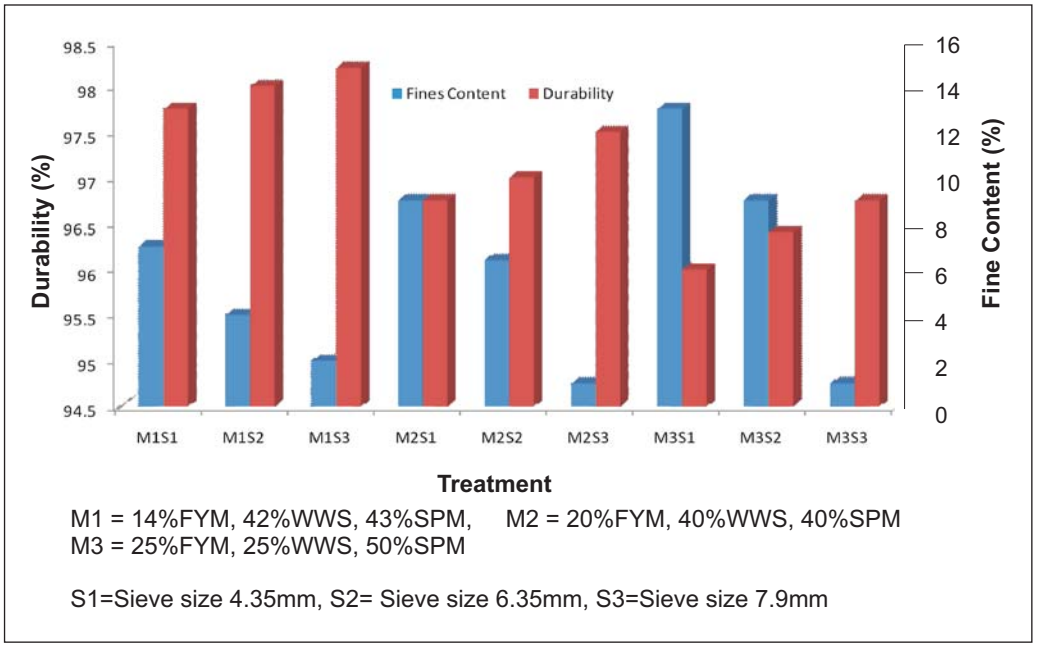

Figure-3: Relation of Sieve Size and Mixing Ratio on Durability and Pellets Fines Content

4. RESULTS AND DISCUSSION

4.1 Effect of Mixing Ratio and Sieve Size on Bulk and Unit Density of Pellets

Unit density of pellets depends on raw organic waste, size of sieve used, and moisture content. Conveyance, handling efficiency and storage space provisions depend on density of pellets. Sufficient storage is needed in order to safely handle a huge supply of pellets stock. Low storage space for high bulk density of pellets is required with greater efficiency [13]. Figure-2 shows the interaction of sieve size and mixing ratio on bulk and unit density of pellets. At constant mixing ratio, bulk density decreased with an increase in the size of sieve opening size. So the sieve size 4.35 mm gave the maximum bulk density at same waste composition. The mixing ratio with less sugar-press mud and sewage sludge portion showed less bulk density of pellets. Waste that comprised of 14 % farmyard manure, 43 % waste water sludge and 43 % sugar-press mud, and passed through 4.35 mm size sieve, gave maximum bulk density.

Unit density increased with decreasing quantity of sugar-press mud and wastewater sludge. Maximum unit density was observed in waste having ratio of 1:1:2, i.e., 25 % farmyard manure, 25 % sewage sludge and 50 % sugar-press mud.

4.2 Effect of Mixing Ratio and Sieve Size on Durability and Fine Content of Pellets

Durability is considered high if it is above 80 %, intermediate when it varies from 70-80 % and low when it is less than 70 % [15]. Low durability is not desired as it troubles the pellet storage and handling. Figure-3 shows the interaction between sieve size and mixing ratio for durability and fines content of pellets. Results showed that durability of pellets increases with increase in sieve size because larger pellets are more compact and dense than smaller ones. Durability of pellets decreases with decreasing amount of wastewater sludge and sugar-press mud. It might be due to the fact that sludge is a sticky material that tightly binds with other materials. Highest durability was achieved with the mixing ratio of 1:3:3, i.e., 14 % farmyard manure, 43 % wastewater sludge and 43 % sugar-press mud, with sieve size of 7.9mm. Pellets with low durability might cause storage and transportation problems because these tends to crumble due to moisture adsorption or due to drop or resistance. Less durability increases the possibility of fracture in pellets [14].

Fines content decrease with increase in sieve size. Fines content was highest in the 4.35 mm sieve. With respect to mixing ratio, fines content increased with increasing the amount of farmyard manure and

decreasing wastewater sludge and sugar-press mud. Mixing ratio 1:1:2 (25 % farmyard manure, 25 % waste water sludge and 50 % sugar-press mud), gave maximum fines content. Maximum fines content was produced in treatment of waste material having ratio 1:1:2 (25 % farmyard manure, 25 % wastewater sludge and 50 % sugar-press mud) with a sieve size of 4.35 mm.

5. CONCLUSIONS

Reusing organic waste is the need of the hour as it not only reduces load on landfills, but also cuts down the depletion of fresh resources. The study showed that organic solid wastes can be reused as soil conditioner using pelletization technique, which not only densified the waste but also improved its other physical properties. The outcome showed that treated pellets can be used as nutrient-supply source, as well as soil conditioner. The pallets have the potential to be used on commercial scale for sustainable solid waste management.

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EMISSION AND ROLE OF BIOGENIC VOLATILE ORGANIC COMPOUNDS IN BIOSPHERE

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ABSTRACT

Plants are an essential part of the biosphere. Under the influence of climate change, plants respond in multiple ways within the ecosystem. One such way is the release of assimilated carbon back to the atmosphere in form of biogenic volatile organic compounds (BVOCs), which are produced by plants and are involved in plant growth, reproduction, defense and other interactions. These compounds are emitted from vegetation into the atmosphere under different environmental situations. Plants produce an extensive range of BVOCs, including isoprenoids, sequisterpenes, aldehydes, alcohols and terpenes in different tissues above and below the ground. The emission rates vary with various environmental conditions and the plant growth stage in its life span. BVOCs are released under biotic and abiotic stress changes, like heat, drought, land-use changes, higher atmospheric CO_2 concentrations, increased UV radiation and insect or disease attack. Plants emit BVOCs in atmosphere in order to avoid stress, and adapt to harsh circumstances. These compounds also have a significant role in plant-plant interaction, communication and competition.

BVOCs have the ability to alter atmospheric chemistry; they readily react with atmospheric pollutant gases under high temperature and form tropospheric ozone, which is a potent air pollutant for global warming and disease occurrence. BVOCs may be a cause of photochemical smog and increase the stay of other GHGs in the atmosphere. Therefore, further study is required to assess the behavior of BVOCs in the biosphere as well as the atmosphere.

Keywords: *BVOCs, Abiotic, Biotic, Atmosphere and Stress*

1. INTRODUCTION

The planet Earth has an integrated and self-sustaining system that is composed of multiple biotic and abiotic components. The Earth system comprises of various sub regions, i.e., biosphere, lithosphere, hydrosphere and atmosphere, in which all components interact and are able to perform chemical, physical and biological reactions in the system. Biosphere is the main region on earth with a range of ecosystems with all bio/geo/chemical cycles [1-2]. It is also accredited that biological processes on land system widely influence the atmospheric system and associated climate, because it exchanges many gases among the land and gaseous spheres, although only CO_2 attains most attention though. Similarly, carbon-related living processes like immobilization and mineralization of carbon capture more consideration [3-5] because of its momentous role in climate system. Beside natural processes, many anthropogenic activities boost up the carbon concentration in atmosphere that induce global warming and climatic shift [3].

Accordingly, the 21st century climate models predicted that overall mean temperature of the globe will rise 1-6°C [6]. This may result in continuous increase CO_2 concentrations in the atmosphere. Furthermore, uplift in temperatures alters the weather pattern, precipitation distribution and rainfall intensity, which cause water scarce conditions, such as drought. Drought occurs when abrupt rain fall patterns bring water scarce situation and high temperatures cause soil water loss through transpiration and evaporation [7].

These all natural and anthropogenic changes exert pressure on ecosystem values that changes altering plant-species distribution and characteristics. Plants being immobile cannot evade environmental stresses in the same way as mobile organisms can [8]. These weather shifts directly affect plant growth, biochemical activity and the length of the active growing season [9], thus plants exhibit varied responses to environmental stresses. Plants adopt various mechanisms to work with increased CO_2 concentration, high temperature and restricted water supply by maximizing water uptake and reducing water loss from the above ground vegetative body. Plant body modifies its biochemical processes to become more tolerant. In such circumstances, plants release certain chemical compounds in atmosphere to defeat environmental stresses. These are known as biogenic volatile organic compounds [2,10,11].

2. BIOGENIC VOLATILE ORGANIC COMPOUNDS (BVOCs)

Biogenic volatile organic compounds (BVOCs) constituted one of nature's many biodiversity treasures. These biogenic compounds are released from natural sources at an estimated rate of 1.1-1.5 Pg C per year globally [16-23], which is greater than anthropogenic emissions [24] and their concentration varies from several ppt (parts per trillion) to ppb (parts per billion), and reactivity span from minutes to hours

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Table-1: Major BVOCs Categories Emitted from Plants

BVOCs group	Average Global Emission (10^{12}gC)	Atmospheric reactivity lifetime (hour)	Atmosphere concentration	Example
Isoprene	175–503	4.8	pmol mol^{-1} to several nmol mol^{-1}	Limonene, 2-Methyl-3-buten-2-ol, hexenal, acetaldehyde Methanol, ethanol, formic acid, acetic acid, acetone
Monoterpenes	127–480	2.4 – 4.8	pmol mol^{-1} to several nmol mol^{-1}	
Other reactive BVOCs	~ 260	<24.0	to several nmol mol-1 1–3 nmol mol^{-1}	
Other reactive BVOCs	~ 260	>24.0	2–30 nmol mol^{-1}	
Etylene	1 – 20	45.6	pmol mol^{-1} to several nmol mol^{-1}	

Source: *[2, 3, 25]*

[15-25]. In harsh environment, plants produce and emit a large number of biogenic volatile organic compounds to reduce stress and to ensure survival for themselves [12-14]. BVOCs cover a wide range of organic species (Table-1), including isoprene, terpenes, hemiterpenes, monoterpenes, sesquiterpenes, isoprenoids and other oxygenated compounds [13,15,16]. Also a variety of low-molecular weight (C<5) BVOCs are released by plants, for example methanol, ethylene, formaldehyde, ethanol, and acetaldehyde [17,19]. So far, almost 1,700 substances have been found that release from various plant body parts [20]. Pluralities of biogenic compounds are lipophilic and, with ample vapour pressure, are capable of entering into the in atmosphere significant concentrations. Plants in unfavorable severe conditions release photosynthetic assimilated carbon back to the environment in the form of BVOCs. In normal circumstances, plants give out upto 2% of their assimilated carbon from leaves in gas exchange [21]. For dealing with multiple stresses, increase in assimilated carbon release may be upto 10 to even 67% in BVOCs production, while the concentrations vary throughout the whole life cycle of a plant [22].

In BVOCs group Isoprenoid (Isoprene and monoterpenes) is considered dominant member emitted by plants [16, 26]. Isoprene is a 2-methy l-1, 3-butadiene, which is mostly produced by few herbaceous and several woody plant species [25]. Isoprene (C_5H_8) and monoterpenes ($C_{10}H_{16}$) are major emitted compounds from vegetation [15,27]. Isoprene production and emission by plants were first described by Sanadze [28] and its effect on the physico chemistry of the atmosphere was first described by Went [29]. Isoprene is quantitatively the most important of the non-methane BVOCs (NMBVOCs), with an annual emission of about 400–600 TgC; about 90% of this is emitted by terrestrial plants. The main environmental controls on isoprene emission are light, temperature and atmospheric CO_2 concentration [30].

3. REGULATION OF BVOCS EMISSION

A broad range of BVOCs are produced of the above in several tissues in above- and below-ground parts of plants. Nearly all parts from vegetative body, as well as flowers and roots [11] emit these compounds in all life stages but their concentrations vary from more obvious at specific developmental stages to their peak on maturation [1,31-33]. Plant leaves have the maximum emission rates throughout a life cycle. Woody plants are more capable of releasing vast mixture of terpenoids, including isoprene, monoterpenes, sesquiterpenes along few diterpenes [34].

BVOCs do not store in plant body, these directly release in atmosphere as produced [12], while In some plants, BVOCs, after production, are accumulated are in leaves and stem compartment in high concentrations that may able to diffuse out of the plant body under biotic and abiotic stress conditions. Thus emission concentration generally relies on existence of leaves and storage compartments [35]. A

few plant species, like Pinus, Abies, Eucalyptus and other members in *Rutaceae* family, accumulate Terpenes in specific storage sections (for example, resin ducts, cavities, oil glands or glandular trichomes). While many others, like some oak species (*Quercus spp.*) are not able to store BVOCs [37]. Isoprene is a major compound emitted from vegetation but it does not get accumulated in plant body, consequently isoprene is not stored in the leaf. Isoprene emission rate thus accurately reflects its instantaneous rate of synthesis [36]. In addition the emission rates of BVOCs are determined by their synthesis rates and by their physicochemical characteristics, including solubility, volatility and diffusivity. However, BVOCs release is attributable to enzymatic activities in both optimum and stress environment [1,38,39].

Emissions of BVOCs are biosynthetically regulated by both environmental and genetic factors [19, 40]. Environmental stresses may induce change in BVOCs composition, concentration, either by inducing or quenching the emissions [11]. Soil water availability, carbon dioxide (CO_2) concentration, light, temperature and other environmental stresses may therefore affect the production and emission of some BVOCs by altering plant physiology, the substrate availability and limiting the enzyme activity. Other BVOCs are produced after injury and feeding by herbivores or after certain environmental stresses. Biotic and abiotic stresses induce BVOC production from leaves, such as terpenes, methyl jasmonate (MeJA) and methyl salicylate (MeSA), and their composition and quantity rely on magnitude and type of stress [1,41, 42]

4. EFFECTS OF ABIOTIC STRESSES

Abiotic stresses prompt and influence BVOC release for plant protection, defense and directly signal the environmental constraint [11]. General stress conditions tend to prohibit photosynthesis by minimizing the CO_2 uptake and diffusion to the fixation site inside leaves. Stress conditions alter biochemical reactions, photosynthetic cycles, and primary or secondary metabolites formation in multiple ways.

Drought: The drought phenomenon is often the natural outcome of heat waves, summer climate, low rain fall and high transpiration rate [11]. Anomalous rain fall pattern and intensity depict more drastic climatic change [43]. Water conservation to evade drought condition in plant body is managed by stomatal closure, reduction in leaf area, root extension for increased water uptake, reduced plant height, controlled transpiration and limited photosynthesis [44-46]. Thus change in abiotic stresses directly influences stomatal conductance and triggers various biochemical and gas diffusion constraints for photosynthetic pathway and production a range of BVOCs [11]. Drought impinges the vegetation in many areas by altering biochemical processes. Modest drought may abate or augment the isoprene and monoterpene emissions. Whereas, prolonged and stern drought conditions result in partial or full inhibition of photosynthesic processes and, eventually, in prominent decline in BVOCs emissions [40]. The diverse behavior in BVOCs release to mild drought may be attributable to leaf physiology; BVOCs biochemistry and plant species. Although, the abatement in photosynthesis and stomatal conductance are anticipated to pose negative effect on BVOCs release by shifting carbon supply into the non-mevalonate pathway. Eventually, volatile terpenes' emission is resistant to stress but it is also known that the emission is often elicited by stress occurrence. Generally, drought situation provokes isoprene synthesis and release [48]. However, it does not reduce with increase in drought [11], either it seems to be unaffected by mild stress for limited time until the stress becomes severe, which almost completely inhibits photosynthesis [48, 49, 50]. On reversing stress conditions opposite results have been observed in BVOCs release pattern.

Temperature: The BVOCs liberation rate is partly determined by leaf temperature. However, leaves emission concentration is not considerably sensitive to leaf physiological attributes, yet it is affected by physiochemical limitations owing to temperature, stomatal conductance, leaf structure and enzymatic chemistry [51]. Temperature is an instantaneous and potent factor which causes enzyme degradation that is involved in BVOCs synthesis. High temperatures create physiological changes in leaf that influence BVOCs emission pattern [12, 16]. Thus, temperature is another influencing abiotic factor that can boost up BVOCs to higher emission level. BVOCs release strongly relies on temperature, since increased temperatures catalyze chemical reaction, cellular diffusion and also raise vapour pressure of BVOCs [52-53]. The balance among gaseous and aqueous chemical phases is regulated by temperature and hence it is assumed that more BVOCs enter the gas phase and are the emitted at high temperatures [11]. This was depicted by Penuelas & Llusia [12] that 2-3°C rise in mean global temperature can surge global BVOCs release by 25-45%. Isoprene synthesis has shown sensitivity to temperature [53] and this

response remains similar to almost all species, though basal emission varies with lead age of specific species because young leaves do not emit isoprene [54]. It was indicated in a case study from the Great Britain that a unit elevation in temperature increase isoprene emissions by 14% in summers and 3°C shift could raise emission by 50%. Isoprene emission shows decrease in concentration with rise in temperature. Generally high temperatures (more than 40°C), show steep drop in concentration of isoprene emissions. It is shown that high temperature promotes photorespiration and stimulate biochemical restriction of photosynthesis. However, physiological factors (stomatal and mesophyll conductance and resistance to CO_2) influence the leaf carbon fixation and effusion (photorespiration, respiration, BVCOs) process [55-56]. Beside this, the plant species that do not store BVOCs into specific storing pools in leaf mesophyll, easily release BVOCs against the concentration gradient along the leaf. Here the only limitation is the stomatal conductance for gas exchange. Rise in mean temperatures often influences the leaf stomatal behavior.

Elevated CO_2: Present and anticipated climatic changes are responsible for raising CO_2 concentration that further brings a rise in temperature, water scarcity and drastic metrological events [6, 58]. From pre-industrial time to the present, the atmospheric CO_2 concentration has raised nearly 35%. It is projected that this increase will double within the 21st century [6]. CO_2 is considered a basic reason of global warming. However, for short time periods the mounting CO_2 concentration can possibly improve plant vegetative growth and photosynthetic efficiency. The primary factor of better growth is the increased substrate availability for Rubisco in photo biochemical processes, consequently bringing enhancement in photosynthesis [11]. At higher concentrations plants release their assimilated carbon in the form of BVOCs, however elevated CO_2 level may cause rise [59], decline [60] or may have no prominent effects on [61] BVOC production and emission at the leaf. Several aspects like plant species, age, experimental duration and CO_2 concentration, may cause shift in the results. Generally, CO_2 is one important factor that uncouples terpenoid formation and release during photosynthesis [11]. It, thus, assists the production and emission of BVOCs.

Atmospheric CO_2 concentration shows influence on major isoprene emissions. A high level of CO_2 induces the photosynthesis process, beside this, isoprene emission is restricted at elevated CO_2 concentration and emission increases at low CO_2 level. Studies on various plant species have revealed the limited isoprene biosynthesis under higher than ambient CO_2 concentrations [11,61]. Regardless of the lower isoprene emission at higher CO_2 level, on balance it may be offset because high CO_2 increases plant biomass and leaf area, which ultimately results in release of more or equal isoprene in atmosphere

5. EFFECT OF BIOTIC STRESSES

Alongwith all abiotic stress factors, various biotic factors induce BVOCs production in plants. Competition among plants of same and different species for biotic resources, like light, water soil nutrients, is one of the most important stress factors. This struggling link among plant communities shapes vegetation composition and regulates biodiversity [1-2]. To get success in competition, plants release a wide range of phenotypical signals to enhance resource capture and, thus, increase their fitness during competition [10]. Apart from plant competition, plant tolerance behaves as another biotic stress. BVOCs release and have capability to modulate tolerance level of plants toward light, heat, oxidative and abiotic stresses, pollutants and can influence plant-plant interaction [3, 10, 40, 62]. BVOCs may also trigger some responses in neighboring plants [10]. The inducible BVOCs also behave as alleles and info chemicals involved in plant–insect and plant–plant interactions in community, while its emission depend on the plant species and genotype as well as on the type of insect inducer [2]. Both biotic and abiotic circumstances both have an impact on BVOCs concentration. Plants that proliferate on limited nutrient soil produce lesser BVOCs concentration than nutrient rich soil upon any herbivore attack [10].

Similarly, photo irradiance influences the emission rate, dense canopies receive less light and it is highly correlated with BVOCs emission [19]. Total BVOC emissions of healthy, undamaged plants are only mildly affected by light intensity, whereas BVOC emissions of herbivore-attacked plants are strongly light dependent [40].

6. ROLE OF BVOCS IN ECOSYSTEM

BVOCs are produced under stressed and non-stressed situations to make plant tolerant and competent. These compounds play significant role in plant growth, metabolism, reproduction, protection and defence [1]. Indeed, their concentration alter by

global climatic alterations, hence affecting the structure and biochemical functions of organisms as well as the communities and system. The previous five years have shown basic modifications in plant, physiology, community interaction and competition. It is seen that volatile hormone ethylene work as an indicator for [10] competing plants and non-competing individuals, both in quality and quantity concern. BVOCs affect plant community in two ways:

- compounds behave as allelopathic that inhibits the plant development; and
- release from plants to give some clue about competitor presence or to exhibit clue about opposing strength.

7. BVOCs ROLE TO ALTER ATMOSPHERIC CHEMISTRY

BVOC have prominent role in biosphere and atmospheric interactions. Plant biologists show interest in BVOCs functions in the biosphere as well as their role in plant biology and ecology [3,5,11].

Atmospheric Chemistry: One of the important considerations of BVOCs is their role in atmospheric chemistry [63, 36] because of their possible interference in the carbon cycle. Among different BVOCs emitted, non-methanic biogenic compounds are of important concern because of their higher reactivity to many important atmospheric oxidants viz: OH•,O_3,NO_3• radicals and also due to their high emission rate, estimated at ~1150 TgC year^{-1}, globally [64]. Specifically, isoprene is known for its role in the formation of blue haze, which are visible over dense forests [29]. Further isoprenes are also involved in the formation of different organic acids and carbon monoxide.

Ozone Formation: Globally, in the form of background concentrations or air pollution the concentration of ozone in the troposphere is likely to increase in coming decades [2]. BVOCs have dual interaction with the ozone in troposphere, such that the effect of ozone on BVOCs emission of the plants is usually dependent on other experimental factors, like temperature and applied ozone concentration, plant species, season and type of BVOCs. The oxidizing potential of many species in the troposphere is also effected by the BVOC emission. Reportedly, the breakdown of BVOCs results in the formation of ground level ozone, known to be major component of photochemical smog [1,2] and also the third most potent GHG (green house gas). At the same time, BVOCs also react with ozone and thus are also crucial in ozone dissociation. Since the formation of ozone at ground level is also dependent upon the presence of NO_x in certain areas, and NO_x are usually present as pollutant in urban areas, therefore the concentration of ozone can readily increase in such areas. Recently, role of BVOCs in formation of ozone has been discussed on continental scale. Important contemplations related to the emission of NO_x, photochemical activity and reduction in ozone through transportation and dry deposition [3,11] have also been made.

BVOCs also result in atmospheric pollution even on un-polluted sites, where the emission of BVOCs has enhanced the concentration of other green house gases, primarily methane. This issue of BVOCs is often linked with their role in decreasing the oxidation capacity of troposphere by interference with OH^- (hydroxyl) radicals, known for their role in atmospheric cleansing through series of oxidation reaction [1, 2,12]. So the change in BVOCs concentration results in differential oxidation in troposphere. Increased level of BVOCs would result in increased the level of ozone and instantaneously the level of methane in the atmosphere. The formation of ozone in the atmosphere by BVOCs emission is usually linked with the presence of unsaturated compounds present in BVOCs, that react with OH• or NO_3 radicals during day and night, respectively. The resultant product is peroxy radical that oxidizes NO to NO_2. The photolysis of NO_2 is initiator of ozone formation thus biogenic volatile organic compounds directly form ozone at polluted sites [64, 65].

Secondary aerosols: Other biogenic compounds usually terpenes (monoterpenes ($C_{10}H_{16}$), sesquiterpenes ($C_{15}H_{24}$) and oxygenated aromatic methyl chavicol ($C_{10}H_{12}O$) also play critical role in atmospheric chemistry because they result in formation of secondary aerosols (SOA), thus contributing to the changing oxidative potential of atmosphere. An important property of BVOCs, to act as cloud condensation nuclei, make them crucial in SOA formation [12] as they produce large quantities of organic aerosols [35]. BVOCs are regarded important in production of SOA [12], as the oxygenated and sized BVOCs emitted from certain species play their role in increasing the size of particles [40]. Among many BVOCs, the emitted terpenoids react rapidly with the oxidants in the atmosphere and result in the formation of aerosols. On lab scale limited number of volatile compounds are known to be produced by ozonolysis of terpenes. This property may be critically

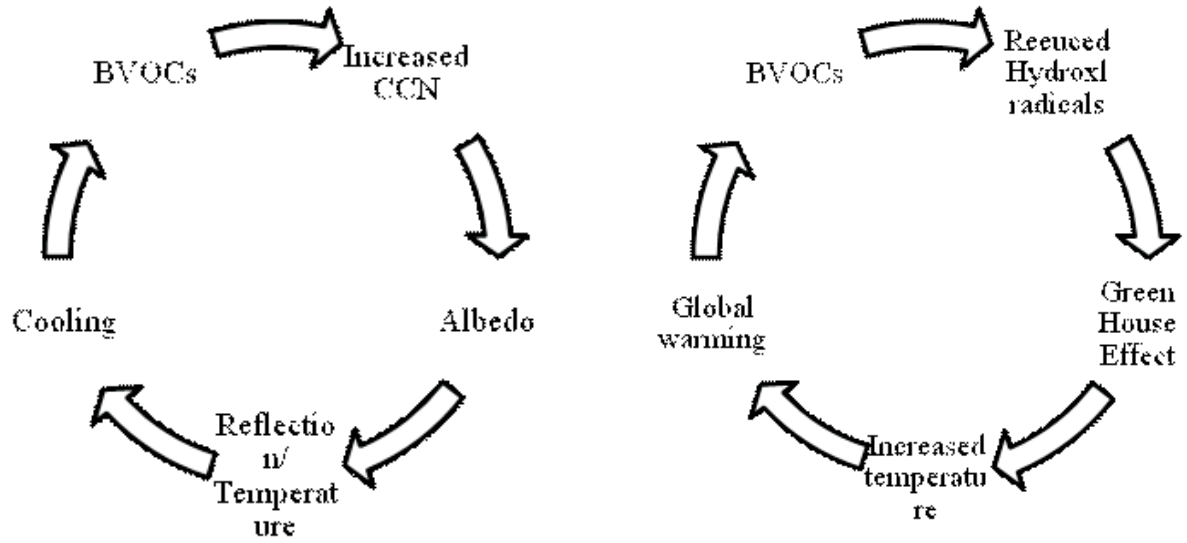

Figure-1: Positive and Negative Feedback Mechanism for Global Warming through BVOCs Emissions

important in the SOA formation due to their role in gas to particle conversion. Under increased concentrations of ozone through anthropogenic activities the problem could further aggravate. Compared to previous decades, BVOCs are now more concentrated in the formation of condensable vapours, SOA and cloud condensation nuclei (CCN) in small duration. The increased level of CCN would lead to cooling of the earth surface as the high concentration of CCN in clouds reduces the opacity of clouds therefore lesser radiations will reach Earth surface. High level of CCN would either directly reduce the albedo of the clouds or affect in the total GHE (green house effect). Thus resulting in overall cooling of Earth's surface, because of reduced net energy budget of solar radiations.

8. BVOCs AND GLOBAL WARMING

Although a probable cooling effect of the SOA is there; the emission of BVOCs is still an impending source of global warming. As discussed previously, BVOCs play their role in production of ozone and increase the lifespan of methane in atmosphere [1,2,12,40], hence exhibiting a positive and negative feedback mechanism (Figure-1).

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MINIMIZING NATURAL GAS CONSUMPTION THROUGH SOLAR WATER HEATING

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ABSTRACT

Natural gas has 43.2 % share in Pakistan's energy-mix, while 18.7 % of the total natural gas is being consumed by the domestic sector. Statistical data shows that over the last ten years gas consumption by the domestic sector has increased from 144 to 232 billion cubic feet. Pakistan is facing extreme shortage of natural gas, especially in winters due to increased demand in domestic sector for space- and water-heating. Utilization of solar energy resource can effectively contribute towards shifting natural gas utilization from domestic to industrial sector of the country. This study helped analyze the quantity of natural gas saved and GHG reduction and economic benefits obtained due to shifting to solar water heating. Results of the study showed that by utilizing single unit of evacuated tube solar water heater in Quetta, 7.7 mmBtu of natural gas can be saved with net present value (NPV) of PKR 243,310 and 10 tones of GHG is saved from entering into the atmosphere.

Keywords: *RETScreen, evacuated tube solar water heater, net present value.*

1. INTRODUCTION

Natural gas is contributing a significant amount to Pakistan's energy mix, and its major portion is utilized in domestic sector (18.7 %). For distribution, domestic sector is being given priority by the government, and its consumption of gas has increased to 232 billion cubic feet. As a result of this, production sector (industry) is suffering greatly, especially in winter season due to excessive utilizations of natural gas for household water heating. Therefore, energy and industry sectors are facing severe gas load shedding. Excessive utilization of fossil fuels to meet increasing energy demands has led to environmental, economic and energy security issues for future regarding these conventional energy resources. Depleting fossil fuel reserves are polluting the environment seriously, as well as causing health problems, reduced life-expectancy and infant mortality (Kampa and Castanas, 2008). Energy sector plays a significant role in this regard as production, distribution and consumption of energy causes environmentally harmful effects. There is, thus, a need to focus on energy resources that are secure, easily available, environmentally favorable and cost-effective.

Geographical location, climatic condition and topography of Pakistan are ideal for utilizing available solar resources that can be conveniently converted using energy conversion technologies. Most parts of the country receives 7.6 hours of sunshine for more than 300 days/year, i.e., 5-7 kWh/(m^2/day) of average solar radiations. These figures indicate that Pakistan is generously blessed in terms of solar potential. This vast solar potential can be utilized beneficially for solar-energy applications, such as solar water heating, photovoltaic, desalination and crop drying (Shaikh, et al., 2013).

Serious energy crisis in the country demand revolutionary steps to be taken with proper planning. In order to improve the economic condition of the country, it is necessary to apportion natural gas for production (industry) and power sectors instead of non-production (domestic) sector. In order to achieve this, some of the domestic hot water demand should be met using solar thermal technologies. Although due to shortage of gas supply and decrease in the price of solar-water heaters, there installations are increasing, but there is still a need for a significant increase.

In this research, RETScreen software was used to analyze the quantity of natural gas saved by using evacuated tube solar water heater in Quetta city. RETScreen software has good research penetration (Connolly, et al., 2010) and researchers have investigated its features in details (Lee, et al., 2012; Markovic, et al., 2011). RETScreen software has been extensively utilized for the analysis of renewable energy technologies in different parts of world (Harder and Gibson, 2011; Thompson and Duggirala, 2009). Literature endorses successful utilization of RETScreen in solar thermal technology as well (Gastli and Charabi, 2011; Stevanovic and Pucar, 2012).

2. CASE STUDY

In order to study the advantages of solar water heating in Quetta city of Pakistan was selected as the target area for research. The annual average daily air temperature of Quetta city is 15.7°C, which is relatively lower than that of many other major cities of the country (Karachi, Hyderabad, Lahore, Multan, Peshawar and Islamabad). This annual average daily air temperature indicates that Quetta has greater heating demand than other cities because of large temperature difference between ambient and required water temperature.

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Figure-1: Pakistan Map Indicating the Position of the Selected City

Table-1: Climatic Conditions of Quetta City

Months	Air temperature (°C)	Relative humidity (%)	Wind speed (m/s)	Earth temperature (°C)
January	3.7	56.0	4.3	6.5
February	6.0	47.5	4.6	9.2
March	11.1	37.7	4.6	15.6
April	16.6	26.1	4.5	23.6
May	21.0	18.4	5.0	29.5
June	25.6	21.0	4.7	33.8
July	27.9	38.3	4.4	34.0
August	26.4	41.9	4.2	32.1
September	21.1	24.4	4.4	28.9
October	14.6	20.3	4.6	21.5
November	9.2	28.1	4.2	14.5
December	5.1	44.5	4.3	8.7

2.1 Climatic Data

Quetta city lies on 30°15'N latitude and 66°55'E longitude, and is the Provincial Capital and largest city of Balochistan Province of Pakistan. The population of the city is around 865,125. Location of Quetta city on Pakistan's map is shown in Figure-1. The detailed analysis of the weather of Quetta city is made from RETScreen software's climate data section (Table-1). The software has unique assistance of obtaining data from ground monitoring stations, as well as NASA's satellite database. The monthly variations of annual daily average solar radiations on horizontal and tilted surfaces are shown in Figure-2.

The temperature data showed that monthly average values of air temperature varied from minimum 3.7°C to a maximum value of 27.9°C; the low annual average values indicated the severity of heating requirement; while the high solar-radiation values indicated good potential for solar energy technologies.

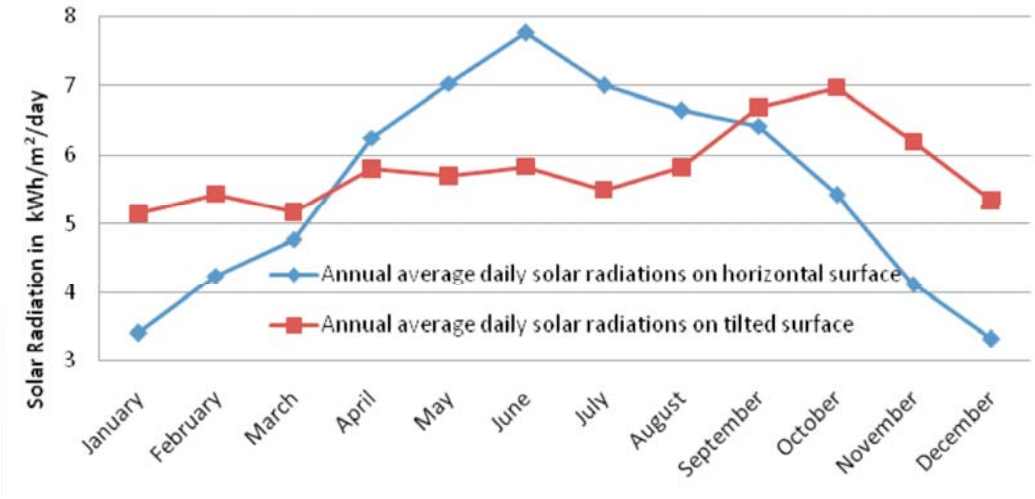

Figure-2 : Annual Average Daily Solar Radiations on Horizontal and Tilted Surfaces

Table-2: Parameter Used in the RETScreen Software

Parameters	Value
Occupants	6
Daily hot water usage (L/day)	300
Hot water temperature (°C)	50
Solar water heater	
Type	Evacuated
Gross area per solar collector (m^2)	1.68
Aperture area per solar collector (m^2)	1.49
Number of collectors	3
Capacity (kW)	3.12
Miscellaneous losses (%)	3
Balance of system & miscellaneous	
Storage capacity per square meter (L/m^2)	75
Fuel type	Natural gas
Financial parameters	
Project life	25 yr

2.2 Software Parameters

RETScreen software has special importance for renewable as well as for solar thermal applications. The software provided comprehensive analysis schemes in a user friendly manner with higher degree of accuracy.

The case study utilizes typical family of 6 members for analysis. In order to ensure hot-water availability, solar water heating system always uses some back up. For this case study, natural gas heating system (natural gas geyser) was taken as backup. The parameters for basic scenario are listed in Table-2.

3. RESULTS AND DISCUSSION

Under this case study, analysis was made as to how much benefits, in terms of saving natural gas units, and net GHG reductions, would be obtained by utilizing evacuated tube solar water heater for a household having a family size of 6 persons. RETScreen had been previously utilized for economic analysis of solar water heating (SWH) projects (Houri, 2006; Fantidis, et al., 2012).

These analyses involved calculations of conventionally utilized natural gas geyser system (base case) compared to solar water heating unit (proposed case). The RETScreen advance energy

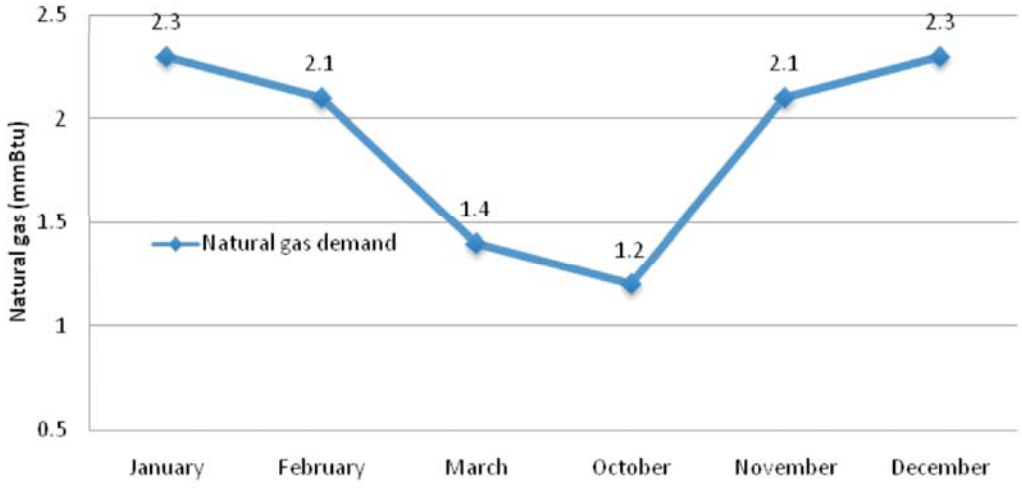

Figure-3 : Natural Gas Demand in Different Months of Winter Season

Table-3: RETScreen Simulation Results

Sr. No	Parameter	Value
1	Solar fraction	67 %
2	NPV	PKR 243,310
3	Equity Pay Back	8.2 Years
4	IRR	15.6 %
5	Gas consumption units (Geyser)	11.4
6	Gas consumption units(SWH)	3.7 mmBtu
7	Net GHG reductions	10 tCO_2

simulations, show the heating energy load for different months of winter season Figure-3. It can be seen that have heating requirements are maximum in December and January, as air temperature is minimum in these months (Table-1); while heating requirements are minimum for the month of October, where air temperature is maximum among selected months of the winter season. Table-3 shows that if natural gas based geyser is replaced with evacuated tube solar water heater, the gas consumption reduces from 11.4 mmBtu to 3.7 mmBtu, and 7.7 mmBtu of natural gas can be saved. It must be noted that if the number of panels are increased the proposed case heating can be reduced. This may not be beneficial in terms of economic parameters and will cause problems in cloudy days when sufficient solar energy is not available and uneven load (extra persons). Figure-2 indicates that our annual heating cost decreases from PKR 6,273 to PKR 2,048 by using solar water heaters. Solar fraction covered by a solar water heater is 67 %, as given in Table-3. The net present value (NPV) of solar water heating unit, internal rate of return (IRR), equity pay back and net GHG reductions are given in Table-3.

These figures show that utilizing a solar water heater is an attractive option to be considered for Pakistan, especially in current situation where natural gas prices have spiked.

3. CONCLUSION

The study investigated a practical solution to overcome the shortfalls of natural gas, which is major energy resource in Pakistan's energy mix. Using the RETScreen software advance energy simulations analysis for typical evacuated tube collector in Quetta, it was found that evacuated tube collector utilization is beneficial in Quetta. If a typical family of six members used evacuated tube collector, it can save more than 7.7 mmBtu of natural gas annually with NPV of PKR 243,310. Moreover, the evacuated tube collector covers 67 % of the total water heating demand.

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