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Designing of Hydraulic Fracture Job and Performance Analysis of Extremely Low Permeability Oil Reservoirs

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Abstract: In case of extremely low permeability reservoirs, stimulation techniques are mostly required to enhance the production of wells. During these times of energy crises unconventional reservoirs have got significant importance. In such situations, proper designing and execution of hydraulic fracture job (HFJ) is required to produce wells at attractive production rates. By using this technique, wells can produce more, resulting in higher production from the reservoirs. In this paper, a hydraulic fracture job has been designed and its impact on oil production has been estimated by performing pre- and post-fracture reservoir performance calculations, using developed SMART software. While conducting this study, effect of varying fracture half-length in extremely low permeability oil reservoirs has been investigated and the impact of the same fracture half-length in varying permeability reservoirs has also been analyzed. The results of this study indicate that propagated fractures increases flow rate of wells. It has also been observed that initially the fracture half-length impacts the production appreciably; however, with further increase, it does not affect the production rate to the same magnitude.

Keywords: Low permeability reservoirs, hydraulic fracture job, reservoir performance, HFJ design

1. INTRODUCTION

It is nearly impossible to produce low permeability reservoirs at economical rates, based on their natural potential. In some cases, tight formations (having natural fractures) and naturally fractured reservoirs can also have low productivity, if the existing fractures are not extended up to the wellbore [1, 2].

Therefore, in such cases hydraulic fracture job is required. In HFJ, fracturing fluid is injected at high pressures, resulting into creating fractures into the formation of varying extensions. Later, when the injection of fracturing fluid stops, the added proppants remain in the fracture, keeping the generated fractures open [3-5]. Thus resulting into increased production rates from a well and in broader sense for a reservoir [4, 6, 7]. The significance of HFJ to increase the well productivity has been demonstrated by a number of field case studies [3, 7, 8]. After implementing hydraulic fracture job, overall impact of results on reservoir production can be analyzed by performing post-frac analysis, in which simulation studies can also be included [6, 9-11].

2. HYDRAULIC FRACTURE JOB DESIGNING AND RESERVOIR PERFORMANCE ANALYSIS

Consider a fracture system in a reservoir as shown in Fig. 1. For designing and modeling of HFJ in such reservoirs, a number of models owing to different technical limitations are available in literature. Namely, PKN, KGD and pseudo 3-D models are some of them [5, 12-14]. KGD model is used, when the required fracture height is greater than fracture half-length, while pseudo 3-D models require information pertaining to overlying and underlying formations (with reference to formation, in which HFJ needs to be executed) [5, 12]. In this study PKN model has been used, in which fracture half-length is kept greater than fracture height. Mathematically [5]:

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After calculating average width of fracture, equivalent skin factor and other major steps involved in calculating the successfulness of hydraulic fracture job are briefly described below, however detailed discussion can be found in literature [4-6, 14-16]. Equivalent skin factor can be calculated by using the following equation [13].

\[
s_f = \frac{\ln \left( \frac{x_f}{r_w} \right)}{1 + 0.18 \ln (\frac{F_{CPD}}{K}) + 0.064 \left( \ln (\frac{F_{CPD}}{K}) \right)^2} - \ln \left( \frac{x_f}{r_w} \right) + 0.55 \ln (\frac{F_{CPD}}{K})
\]

Where,

\[
F_{CPD} = \frac{k_w}{k_x}
\]

The folds of increase in productivity index as a result of HFJ can be calculated by using the following equation [12].

\[
\frac{J}{J_0} = \frac{\ln \left( \frac{P_w}{P_r} \right)}{\ln \left( \frac{P_w}{P_r} \right) + s_f}
\]

After that pre- and post-frac reservoir performance can be analyzed by using equations, which are selected based on reservoir pressure. If \( P_r \geq P_b \), then straight line inflow performance relationship (IPR) is used for predicting reservoir performance, which can be written as [13]:

\[
q = J \left( P_r - P_{wf} \right)
\]

and if the reservoir pressure is below bubble point or declines below the bubble point pressure, then vogel equation can be used [13].

\[
q = q_{max} \left[ 1 - 0.2 \left( \frac{P_{wf}}{P_r} \right) - 0.8 \left( \frac{P_{wf}}{P_r} \right)^2 \right]
\]

or,

\[
q = q_b + \frac{P_b}{1.8} \left[ 1 - 0.2 \left( \frac{P_{wf}}{P_b} \right) - 0.8 \left( \frac{P_{wf}}{P_b} \right)^2 \right]
\]

For analyzing reservoir performance before and after HFJ, same set of equations are used, while incorporating pre- and post- value of productivity index.

## 3. IN-HOUSE DEVELOPED SMART SOFTWARE FOR HFJ DESIGN AND RESERVOIR PERFORMANCE ANALYSIS

To design HFJ and to predict reservoir performance, a SMART software has been developed. This software also gives an option to estimate and perform sensitivity analysis. The developed algorithm can be explained with the help of flow chart as shown in Fig. 2.

## 4. CASE STUDIES

Hydraulic fracture job is designed and later reservoir performance has been predicted by using above discussed methodology for extremely low permeability oil reservoir having a depth of 8000 ft. The permeability of a reservoir was varied from 0.085 to 0.9 md and fracture half-lengths were 100, 150 and 200 ft. Further details of reservoir and proppant properties are given in Table 1.

### Table 1. Input data used in SMART software for HFJ design and reservoir performance analysis.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>8000 ft</td>
</tr>
<tr>
<td>Diameter of tubing (ID)</td>
<td>2.259 in</td>
</tr>
<tr>
<td>Pipe relative roughness</td>
<td>0.0006</td>
</tr>
<tr>
<td>Minimum horizontal stress</td>
<td>6300 psi</td>
</tr>
<tr>
<td>Maximum horizontal stress</td>
<td>8865 psi</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>1095 psi</td>
</tr>
<tr>
<td>Formation pressure</td>
<td>6900 psi</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>0.25</td>
</tr>
<tr>
<td>Shear strain</td>
<td>0.75</td>
</tr>
<tr>
<td>Wellbore radius</td>
<td>0.5 ft</td>
</tr>
<tr>
<td>Proppant permeability</td>
<td>250,000 md</td>
</tr>
</tbody>
</table>

The calculations have been performed, firstly by keeping the reservoir permeability constant and varying the fracture half-length (Case 1) and later the effect of constant fracture half-length has been investigated by varying the formation permeability (Case 2). The obtained results are shown in Fig. 3 to 5 for Case 1 and from Fig. 6 to 8 for Case 2.

Fig. 3 to 5 show that with the increase in fracture half-length, i.e., as the penetration of the fracture within the reservoir increases, oil production also increases for the same wellbore flowing pressure. With the increase in fracture half-length, the production rate increases, but that increase in rate is not proportional with the increase in \( x_p \) or in other words with the equal increase in fracture
Fig. 1. Schematic diagram of propagated fracture and associated parameters.

Fig. 2. Algorithm for developed SMART software.
Fig. 3. Pre- and post-frac reservoir performance at $k = 0.085$ md and varying $x_f$.

Fig. 4. Pre- and post-frac reservoir performance for reservoir permeability of 0.5 md.
Fig. 5. Pre- and post-frac reservoir performance for $k = 0.9$ md.

Fig. 6. Reservoir performance prediction for varying permeability and constant $x_f$ (100 ft).
Fig. 7. Reservoir performance prediction for varying permeability and $x_f = 150$ ft.

Fig. 8. Reservoir performance prediction for varying permeability and $x_f = 200$ ft.
half-length, the increase in production rate does not increase with the same ratio.

In this study it has also been analyzed that how the increase in reservoir permeability can decrease the required fracture half-length, while maintaining the same flow rate (Case 2), as shown in Fig. 6 to 8. The pre-frac analysis remains the same and the results of post-frac analysis changes with the change in reservoir permeability. These figures show that as the permeability of reservoir increases from 0.085 to 0.9 md, the required fracture half-length to produce oil, approximately at the same rate, decreases. For, example, \( x_f = 200 \text{ ft} \) is required when permeability is 0.5 md, but \( x_f = 150 \) is required, when permeability is increased to 0.9 md, to achieve a production rate of 488 stb/day.

The results are summarized in Table 2 and 3. Table 2 gives a comparison of pre- and post-frac productivity index values. The table shows that after hydraulic fracturing the productivity index or reservoir constant has been increased. While, Table 3 shows that how much folds of increase in production is obtained as a result of creating fractures of varying half-lengths in a same permeability reservoir/formation. The table shows that with the increase in fracture half-length, flowrate becomes more than double as compared to pre-frac results. It can also be depicted that in lowest permeability formation, the impact of fracture half-length is more significant as compared to higher permeability formations.

Table 2. Effect of fracture half length on productivity index.

<table>
<thead>
<tr>
<th>Formation Permeability (md)</th>
<th>Fracture Half-Length, ( x_f ) (feet)</th>
<th>Productivity Index, J (Stb/Day/Psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-Frac</td>
<td>Post-Frac</td>
</tr>
<tr>
<td>0.085</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td>150</td>
<td>0.08</td>
<td>0.08</td>
</tr>
<tr>
<td>200</td>
<td>0.084</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>0.08</td>
<td>0.08</td>
</tr>
<tr>
<td>150</td>
<td>0.03</td>
<td>0.085</td>
</tr>
<tr>
<td>200</td>
<td>0.09</td>
<td></td>
</tr>
<tr>
<td>0.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>0.08</td>
<td>0.08</td>
</tr>
<tr>
<td>150</td>
<td>0.04</td>
<td>0.09</td>
</tr>
<tr>
<td>200</td>
<td>0.1</td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Effect of fracture half length on production rate in terms of folds of increase.

<table>
<thead>
<tr>
<th>Permeability (md)</th>
<th>Fracture Half-Length, ( x_f ) (feet)</th>
<th>Dimensionless Fracture Conductivity, ( F_{cd} )</th>
<th>Folds of Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.085</td>
<td>100</td>
<td>59.583</td>
<td>2.65</td>
</tr>
<tr>
<td></td>
<td>150</td>
<td>44.028</td>
<td>3.03</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>35.417</td>
<td>3.37</td>
</tr>
<tr>
<td>0.5</td>
<td>100</td>
<td>11.917</td>
<td>2.46</td>
</tr>
<tr>
<td></td>
<td>150</td>
<td>8.806</td>
<td>2.74</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>7.083</td>
<td>2.96</td>
</tr>
<tr>
<td>0.9</td>
<td>100</td>
<td>6.62</td>
<td>2.34</td>
</tr>
<tr>
<td></td>
<td>150</td>
<td>4.892</td>
<td>2.57</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>3.935</td>
<td>2.75</td>
</tr>
</tbody>
</table>

5. CONCLUSIONS

Hydraulic fracture job plays a significant role in increasing the production from extremely low permeability oil reservoirs. The developed SMART software efficiently designs HFJ and is capable of performing pre- and post-frac analysis. The obtained results show that with the increase in fracture half-length, the production from a reservoir having any permeability also increases. But the percentage increase in production decreases with reference to further increase in \( x_f \), therefore an optimum value of fracture half-length should be selected. It has also been observed that the hydraulic fracture job is more feasible in terms of flow rate increase in tighter formations on comparative basis. Therefore, proper designing and execution of HFJ coupled with reservoir performance analysis can provide/act as an attractive solution to increase the production rates of wells in extremely low permeability oil reservoirs.

6. NOMENCLATURE

\( F_{cd} \) Dimensionless fracture conductivity  
\( J \) Productivity index  
\( J_o \) Original productivity index  
\( k \) Formation permeability  
\( k_f \) Fracture permeability  
\( P_b \) Bubble point pressure  
\( P_R \) Reservoir pressure
P_{wf} Reservoir pressure
q Production rate
q_b flowrate at bubble point pressure
q_{max} Maximum production rate
r_e External/ drainage radius
r_w Wellbore radius
s_f Equivalent skin factor
w fracture width
Average fracture width
x_f Fracture half-length

7. REFERENCES
Assessment of Operation and Catastrophic Risks of Transport Gasifier Pilot Plant

Shahid Naveed, Naveed Ramzan* and Anam Asghar

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Abstract: The assessment of operating failures and catastrophic risks of high temperature and high pressure circulating fluidized bed transport gasifier (CFB-TG) is presented. The safety analysis is based on the guide words set of a typical HAZOP study. CFB-TG pilot plant consisted of coal feeding arrangement, gasification column (riser), a dis-engager, a cyclone and gas handling system (scrubber). Safety analysis supported by the guide word technique starts with the detail study of the process, breaking down the process flow diagram into three nodes (coal feeding system, gasification loop, gas cleaning & cooling). For each node, deviations by using guide words highlighted by the team members with subsequent causes, consequences and corresponding safeguards were tabulated in HAZOP work sheets. The operational failures and catastrophic risks include explosion, noise pollution, gas emissions, ignition of coal in the feed line, back flow of gases, and feed line blockage, syngas failure at the outlet of gasifier, L-valve blockage, air supply cut off, and high moisture content of the feed. Hence, this step by step examination of process by guide word technique led to the modification in P & ID like installation of low and high pressure alarms and switches, level and temperature indicators, alarm systems, non-return valves as preventive measures to avoid operational and catastrophic failure.

Keywords: Operational failure, transport bed, deviation, guide words, HAZOP

1. INTRODUCTION

Transport bed gasifier for coal gasification is becoming a popular technology as higher through puts and efficient mass and heat transfer rate can be achieved. The operation at high temperature and high pressure can be dangerous. The identification and assessment of various operating failure and catastrophic risks is essential. HAZOP is a standard technique to identify the possible risks and hazards of chemical process plant. It is used in various process industries e.g. petrochemical, refinery, gas paper, power processing, mineral, mining, dairy, pulp industry [1]. In fact, HAZOP is the focus of much research aimed at improving the safety of chemical plants that increasingly operate at high temperatures and pressures and encompasses more sophisticated processes [2-3]. A hazard and operability study when applied to gasifier is identified to be a suitable approach for identification of the highest risks [4].

The potential hazards during operation of transport bed gasifier are due to the toxic and explosive mixture of gases that are produced. The syngas gas and residues may cause the risks like explosion and fire. Human health risks like pollution, noise, poisoning, hot surfaces, danger of suffocation within the plant vicinity requires the assessment of risks independently and collectively. The potential occupational hazards in various unit operations of the gasification plant are summarized in Table 1 [5].

The work presented here is part of safety studies for a typical Transport bed gasifier pilot plant in Pakistan. In order to identify the deviations and subsequent causes and consequences the HAZOP approach of guide word technique was adopted.
The high temperature and high pressure circulating fluidized transport gasifier (CFB-TG) operating at 1000 °C and 100 psig is located in an educational environment, so the HAZOP studies have gained further importance to ensure the safety of the community and students.

**Table 1.** Potential occupational health & safety hazards of coal gasification plant.

<table>
<thead>
<tr>
<th>Unit Operation</th>
<th>Potential Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal handling and preparation</td>
<td>Coal dust, noise, fire</td>
</tr>
<tr>
<td>Coal feeding</td>
<td>Coal dust, noise, gaseous toxicants, blockage</td>
</tr>
<tr>
<td>Gasification operations</td>
<td>Coal dust, high pressure, hot raw gas, high pressure oxygen, high pressure steam, fire, noise, back fire, explosion</td>
</tr>
<tr>
<td>Gas cooling</td>
<td>High pressure, raw hot gas, hot gas liquor, heat stress, noise</td>
</tr>
<tr>
<td>Particle separation</td>
<td>Blockage of disengager, cyclone, back flow pipe (stand pipe), Loop seal blockage</td>
</tr>
<tr>
<td>Burner assembly &amp; recycle</td>
<td>Leakage of syngas, pilot or main burner failure.</td>
</tr>
</tbody>
</table>

### 1.1 Process Description

The plant consisted of a coal feeding arrangement, gasification column (riser), a disengager and a cyclone to separate the solids and the synthesis gas. Solids, including ash and unburned/unpyrolysed material, are returned to the tubular gasification column through a return pipe (stand pipe). A specially designed loop seal and L-valve is used to regulate the flow of the recycle material. A fraction of this material is collected in an ash canister. The synthesis gas available is cleaned through a scrubber and cooled through a heat exchanger. The synthesis gas thus made available can be used for various applications including production of liquid fuels, firing in steam power plant for power generation etc. The P&ID of the pilot plant is given in Fig. 1. The brief operating procedure of the plant is given below:

- Fill the stand pipe with inert material (ash and sand) through the filling port FP1.
- Pressurize the gasifier with nitrogen to 100 psig with all valve closed except V5.
- Fill the hopper with the premixed feed of sorbent and coal with the valve V1 closed and pressurize it to 110 psig with all operating valves closed.
- Open valve V14, start pump P1 to stabilize the circulation rate in the scrubber.
- Open three way valve V20 to allow the flow rate of gas towards flare.
- Ignite the pilot burner APB1 to ignite any combustible gas when released through pipe from scrubber.
- Switch on the compressor B1 and heater H1 to supply the heated compressed air to the gasifier at 100 psig. The air is allowed to release slowly through V25, V26 to start the fluidization process in the gasifier.
- Open the rotary valve V1 and start driven motor of feeding system at low feeding rate to feed the gasifier and burn high pressure pilot burner HPB1 in gasifier to allow the stabilization in the temperature in the gasifier.
- Make sure that the hot gases via three way valve V20 should be released to flare to avoid the pressure built-up. Switch on the recycle syngas blower B-1 and adjust three way valve V20 to allow the recycle of the gases from the flare line in a specified ratio to maintain pressure of 100 psig in the gasifier.
- For shutting down, close the valve V1 and switch off coal feeding motor M1 to stop the feeding supply. Close the valves V8, V9, V10, and V5 thereafter. Monitor the temperature of the gasifier as it declines to less than 300 °C. Switch off the air heater H1 and do not switch off the blower B1 until the whole system is cooled down to sufficiently low temperature. Keep blower B2 running. Purge the system with inert gas by opening valve V20 to atmosphere. Switched off the recycle gas blower B1 and water circulation pump P1.

### 2. HAZOP METHODOLOGY

HAZOP is a rigorous and highly disciplined procedure to identify the gaps in operability and process risks that account for safety. The success lies in strength of the methodology to follow system process flow diagram (PFD) and piping and
Fig. 1. P & I D of CFB-TG.
instrumentation diagram (P & ID). As a first step the PFD is broken down into sections with defined boundaries to ensure the analysis of each section in the process [6-7]. Having determined the possible deviations, the next step is to identify the subsequent cause-consequences and safeguards to prevent, control or mitigate the hazardous situation. A set of “guide words” is used at the design stage. When the plant alterations or extensions are to be made on an existing facility a similar procedure is helpful. For this purpose, a team of five to eight people with diverse skills and experience of process, engineering discipline, management and plant operation etc is formed [3]. The examination procedure starts with the full description of the process which includes P & ID and systematically questions through guide words, every part of it to discover deviations and determine whether these deviations can give rise to hazards. The potential problems are then noted for remedial action. The immediate solution to the problem may not be obvious and could need further consideration either by a team member or perhaps a specialist. All decisions taken are to be recorded. The major steps involved in studying guide word technique for CFB-TG are shown in Fig. 2.

**Table 2.** Guide words used to identify risks/operating problems.

<table>
<thead>
<tr>
<th>Guide Words</th>
<th>Meaning</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO</td>
<td>Complete negation, e.g. of intention</td>
<td>No forward flow when there should be</td>
</tr>
<tr>
<td>HIGH</td>
<td>Quantitative increase</td>
<td>More of any relevant physical property than there should be (e.g. higher flow, temperature, pressure, viscosity, etc. also actions: heat and reaction).</td>
</tr>
<tr>
<td>LOW</td>
<td>Quantitative decrease</td>
<td>Less of…(as above)</td>
</tr>
<tr>
<td>AS WELL AS</td>
<td>Quantitative increase</td>
<td>All design and operating intentions are achieved together with some addition (e.g. impurities, extra phase…)</td>
</tr>
<tr>
<td>PART OF</td>
<td>Quantitative decrease</td>
<td>Only some of intention are achieved, some are not</td>
</tr>
<tr>
<td>REVERSE</td>
<td>Opposite of intention</td>
<td>Reverse flow or chemical reaction (e.g. inject acid instead of alkali in pH control)</td>
</tr>
<tr>
<td>OTHER THAN</td>
<td>Complete substitute or miscellaneous</td>
<td>No part of original intention achieved, something quite different occurs.</td>
</tr>
</tbody>
</table>
### Assessment of Operation and Catastrophic Risk of Gasifier

Table 3: Example HAZOP work sheets for different Nodes.

<table>
<thead>
<tr>
<th>Sheet No:</th>
<th>Date: 10-09-2009</th>
<th>Node Function: Gasifier</th>
<th>Design Intent: Combustion of Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Node: 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parameter: Pressure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sr. No</td>
<td>Deviation</td>
<td>Causes</td>
<td>Consequence</td>
</tr>
<tr>
<td>---------</td>
<td>-----------</td>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>1</td>
<td>High</td>
<td>-Outlet line of vessel blocked</td>
<td>-Reverse flow -PSV operates and release gases in atmosphere -Reverse flow in L Valve</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>Feed line blocked</td>
<td>-Gasification slow down -Ash sucked in</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sheet No:</th>
<th>Date: 10-09-2009</th>
<th>Node Function: Supply of Coal and Sorbent</th>
<th>Design Intent: Pressurized Operation (100 psig)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Node: 1</td>
<td></td>
<td>Supply of Feed (Coal and Sorbent) to Gasifier</td>
<td>Design Intent: 3 gm/sec</td>
</tr>
<tr>
<td>Parameter: Level of Coal (Quantity in feed hopper)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sr. No</td>
<td>Deviation</td>
<td>Causes</td>
<td>Consequence</td>
</tr>
<tr>
<td>---------</td>
<td>-----------</td>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>1</td>
<td>Low</td>
<td>-Withdrawal rate high</td>
<td>-feed hoppers get empty -vacuum created -fuel supply is interrupted</td>
</tr>
<tr>
<td>2</td>
<td>High</td>
<td>Not relevant</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>As well as</td>
<td>Not relevant</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Part of</td>
<td>Not relevant</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sheet No:</th>
<th>Date: 10-09-2009</th>
<th>Node Function: Supply of Coal and Sorbent</th>
<th>Design Intent: Pressurized Operation (100 psig)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Node: 1</td>
<td></td>
<td>Supply of Feed (Coal and Sorbent) to Gasifier</td>
<td>Design Intent: 3 gm/sec</td>
</tr>
<tr>
<td>Parameter: Storage Pressure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sr. No</td>
<td>Deviation</td>
<td>Causes</td>
<td>Consequence</td>
</tr>
<tr>
<td>---------</td>
<td>-----------</td>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>1</td>
<td>Low</td>
<td>-N2 Supply cut off -Leakage in vessel</td>
<td>- Reverse flow possible and may lead to explosion</td>
</tr>
<tr>
<td>2</td>
<td>High</td>
<td>-N2 Supply valve failed open -Operator set high falsely</td>
<td>-Vessel may rupture -Excessive feed flow</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sheet No:</th>
<th>Date: 10-09-2009</th>
<th>Node Function: Supply of Feed (Coal and Sorbent) to Gasifier</th>
<th>Design Intent: 3 gm/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Node: 2</td>
<td></td>
<td>Supply of Feed (Coal and Sorbent) to Gasifier</td>
<td>Design Intent: 3 gm/sec</td>
</tr>
<tr>
<td>Parameter: Flow Rate of Coal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sr. No</td>
<td>Deviation</td>
<td>Causes</td>
<td>Consequence</td>
</tr>
<tr>
<td>---------</td>
<td>-----------</td>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>1</td>
<td>Low/Less</td>
<td>-Syn gas failed Line plugged -No coal in feed hopper -Valve V1 or V2 stuck close Vessel -Higher pressure in gasifier</td>
<td>-Gasification die out</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>High</td>
<td>-N2 Supply valve failed open -Operator set high falsely</td>
<td>-Vessel may rupture -Excessive feed flow</td>
</tr>
</tbody>
</table>
Table 3 (Contd.)

<table>
<thead>
<tr>
<th>Sheet No: 2/3</th>
<th>Node: 2 (Feed Line)</th>
<th>Parameter: Pressure</th>
<th>Node Function: Supply of Feed (Coal + Sorbent) to Gasifier</th>
<th>Design Intent: 3 gm/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sr. No</td>
<td>Deviation</td>
<td>Causes</td>
<td>Consequence</td>
<td>Probability of occurrence</td>
</tr>
</tbody>
</table>
| 1 | High | Line is plugged | - Line may leak or rupture  
- Nitrogen/Steam may cut off to gasifier | <1 % | Pressure gauge |
| 2 | Low | - Compressor B01 fail  
- Nitrogen supply ends  
- Steam may exhaust | | | |

<table>
<thead>
<tr>
<th>Sheet No: 3/3</th>
<th>Node: 2</th>
<th>Parameter: Temperature</th>
<th>Node Function: Supply of Feed (Coal + Sorbent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sr. No</td>
<td>Deviation</td>
<td>Causes</td>
<td>Consequence</td>
</tr>
<tr>
<td>1</td>
<td>Low</td>
<td>Irrelevant</td>
<td></td>
</tr>
</tbody>
</table>
| 2 | High | Conduction from gasifier  
Back flow of gases | - May ignite coal in feed line  
- May cause explosion  
- NRV may damage | <5 % | Pressure monitoring and NRV is installed |
| 3 | As Well | | | | |
| 4 | Part of | | | | |

Sheet No: 1 | Node: 2 | Date: 10-09-2009 | Node Function: Dis-engage Design Intent: Dust Removal |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sr. No</td>
<td>Deviation</td>
<td>Causes</td>
<td>Consequence</td>
</tr>
</tbody>
</table>
| 1 | High | High pressure in gasifier | Dust separation efficiency drops.  
More flow in Loop seal leads to increase in circulation through L valve. | <1 % | | |
| 2 | Low | Low pressure in gasifier | Dust separation efficiency drops.  
Reduced flow through Loop seal shall plug it and level of solids shall increase in J Leg. | <1% | | |

Sheet No: 1 | Node: 6 | Date: 10-09-2009 | Node Function: Scrubber Design Intent: Cooling of Syn. Gas |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sr. No</td>
<td>Deviation</td>
<td>Causes</td>
<td>Consequence</td>
</tr>
</tbody>
</table>
| 1 | Leakage or rupture of tube/pipe  
High pressure in pipe due to pipe blockage or clogging of filter in the outlet line | - Release of syn. Gas may caught fire in presence of ignition source  
- Depressurize the upstream system | <1% | - Pressure monitoring  
- Regular inspection | |
| 2 | Failure of fan compressor  
-power failure  
-motor burn out | No cooling results to hot gases may damage candle filter | <10% | | |

Sheet No: 1 | Node: 5 | Date: 10-09-2009 | Node Function: Collect Ash Design Intent: Remove Ash + Sand |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sr. No</td>
<td>Deviation</td>
<td>Causes</td>
<td>Consequence</td>
</tr>
<tr>
<td>1</td>
<td>High Temp.</td>
<td>Cooling water failure</td>
<td>- Vessel may damage</td>
</tr>
<tr>
<td>2</td>
<td>High Pressure</td>
<td>Air vent blocked</td>
<td>Hammering occurs</td>
</tr>
</tbody>
</table>
3. PROCESS IMPLEMENTATION

The systematic process implementation requires critical study of the plant. For the evaluation of credible unfavourable, and potentially hazards situations and subsequent consequences, process flow diagram (Fig. 2) was divided into following nodes: (1) Coal feeding system; (2) Gasification loop; and (3) Gas cleaning and cooling as per the requirement of the selected technique discussed in previous section. The guide words that are planned for the safety analysis are given in Table 2 [8].

Node 1

The portion of process flow diagram undertaken in this section was coal feeding system. Started from feed hopper the parameters that were observed to be investigated by expert team members were storage pressure and level of coal in the storage hopper. And it was reported that level indicator on hopper and high and low pressure switches and alarms on N₂ supply line were missing in the available P & ID. After documenting the recommendations, pressure and flow rate in the feed line were analyzed. The reported possible causes of the failure and hazards were coal supply failure, high pressure in the gasifier, feed line plugging & failure of compressor that may result in back flow of the gasses, rupture of vessel, excess feed flow, rupture or leakage of line and nitrogen cut off respectively. Next parameter that was selected for safety analysis was temperature in the feed supply line. As a result of the high temperature, ignition of coal might be possible in the feed line or it may cause explosion. To avoid this potential hazards and operational failures, installation of high pressure alarm in the feed line, NRV, pressure gauge and pressure monitoring were recommended.

Node 2

Gasifier (riser), disengager and cyclone separator were discussed in this node. The first unit selected for safety analysis was gasifier by taking composition and pressure into account. After step by step analysis through guide words, parameters selected for examination were high moisture content, high sulphur content, high and low pressure respectively with potential consequences of external heating requirement, longer time to achieve steady state, formation of sulphur dioxide, reverse flow of gases from riser and feed line blockage (with low pressure in gasifier). Flow rate of gases was only parameter while discussing disengager and cyclone separator. The potential causes of the deviation were high and low pressure in the gasifier which causes the operation failure like drop in dust separation efficiency, more flow in loop seal and reduced flow through the loop seal, respectively.

Node 3

While analyzing scrubber the deviations highlighted in this node were the leakage/rupture of tube, failure of fan compressor, high temperature and high pressure for the design intent of syngas cooling and ash removal respectively. The potential consequences of deviations observed were syngas release, ignition of coal, damaging of vessel and hammering, respectively.

The sample work sheets for different nodes is shown in Table 3.

3.1 Operational Failure

Node analysis of guide word technique has highlighted many operational failures like back flow of the gases from gasification unit to feed hopper because of the pressure difference, interruption of fuel supply because of no feed in the hopper, syngas failure at the outlet of gasifier (gasification die out), air supply failure to the gasifier, high temperature of the scrubbed gas at the outlet of the scrubber because of cooling water failure. These are the operational failures that were highlighted in safety analysis of the CFB-TG and to prevent these failures and recommendations were suggested which have been discussed in this paper under the heading of safeguards and recommendations.

4. RECOMMENDATIONS

The guide word methodology was implemented on CFB-TG to investigate the operation and catastrophic risks and following recommendations are made:

1. A level indicator on feed hopper may be installed, which was missing in the available flow sheet. In the absence of it, if the withdrawal
rate of feed is high then vacuum may be created or supply of fuel may be interrupted.

2. To prevent reverse flow of gasses, explosion, rupture of vessel and excessive feed flow, install low and high pressure switch/alarm, PSV on feed hopper.

3. Install alarm, NRV, high pressure alarm, PSV and pressure gauge in the feed line. As syngas failure, high pressure in the gasifier, no coal in feed hopper result in the back flow of gases, excessive feed flow, ignition of coal in feed line, vessel rupture and gasification reaction failure. For available P & ID, inspection of alarms, NRV was recommended and high pressure alarm and PSV was missing.

4. Provision of external heating in plant facility and addition of sorbent in the feed was also suggested as safeguards. Because longer time to achieve steady state, more external heating, formation of SO$_2$ and toxicant in ash are the results of high moisture and sulphur contents.

5. Regular pressure monitoring and inspection and cooling water flow rate regulation were also recommended for scrubber section of available plant facility to avoid pipe blockage, cooling water failure.

The above stated recommendations, modified as per outcomes of the subsequent detailed analysis, have been accommodated and considered in the process and instrumentation diagram. The changes with reference to alarms, regulators, safety valves and regular inspection have eliminated the serious causes of accidents, explosion and hazard to the plant personnel, the public or environment.

5. ACKNOWLEDGEMENTS
The authors thank the Chemical Engineering Department, University of Engineering & Technology, Lahore for providing the opportunity and requisite materials to conduct this research work.

6. REFERENCES
Public Perceptions to Travel Demand Management Measures in Lahore, Pakistan: Analysis and Implications

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2Faculty of Regional Development Studies, Toyo University, 2-36-5, Hakusan, Bunkyo-ku, Tokyo, 112-0001, Japan
3Department of Civil Engineering, Yokohama National University, 79-5 Tokiwadai, Hodogaya-ku, Yokohama, 240-8501, Japan

Abstract: This study aims to analyze travel behavior pattern, and identify the nature of relationships among socio-economic demographics (SEDs) and travel demand management (TDM) measures. A questionnaire survey was conducted in Lahore, Pakistan and 631 samples were collected. Initially, cross analysis of vehicle ownership and modal share was conducted to classify the sample into four segments, i.e., car oriented, motorcycle oriented, public transport oriented, and non-motorized modes oriented. The results of cross analysis indicated that the use of cars increased with an increase in education level, and decreased with size of the households. People having private vehicles prefer to use those, instead of availing public transport. However, most of the private vehicle users have favorable evaluation of public transport improvement strategy. Perceptions for TDM measures vary among the four segments of mode users. Optimal ranking of TDM measures places advance traffic information and public transport improvement at the top, and parking charges and fuel tax at the bottom. Ordinal regression analysis was conducted by applying Logit model, and relationships were determined among various SED variables and TDM measures. Modeling results revealed that income, education, gender, and current travel mode are significant determinants of commuter’s attitudes towards the selected TDM measures. Among all factors, respondent’s education level was observed to be the most influencing factor. However, different SED factors affect the consideration of TDM measures differently. The results of this study can help the transport planners and policy makers in arriving at appropriate TDM measures for specific segment of the travel market.

Keywords: Travel demand management, travel behavior, SEDs, public perception, traffic congestion, Lahore

1. INTRODUCTION
1.1 Background
The rapid increase in car ownership and its usage has resulted congestion related problems in developing cities. Other factors that contribute in resulting traffic congestion are people’s disorder driving behaviour, limited supply of infrastructure, inefficient use of existing facilities and absence of traffic enforcements. The trend of using private vehicle tends to shape the cities as auto dependent. Travel demand of passengers has increased rapidly and leading to complexity of handling the situation effectively. The imbalance between demand and supply has resulted road congestion, thus condensing the urban mobility. It is unfair to build more road infrastructure just to facilitate car users and neglecting the mobility of poor people...
such as non-motorized and public transport mode users. In developing countries, the main focus is on supply side measures to meet the increased demand of travel. However, lack of space and technical abilities, lacking in financial and institutional resources, and environment sustainability related problems have forced to look for demand side solutions with supply side solutions. In this context, Travel demand management (TDM) measures are considered as effective tools in influencing the travel behaviour and have impact on reduction in travel time and cost, and convenience of travel options [1]. It is vital to promote such policies that should reduce the advantage of car use and increase benefits of public transport usage [2]. TDM strategies are mainly classified into two categories such as push or disincentive measures aiming to reduce the advantages of car use (e.g. increase in fuel and road taxes), and pull or incentive measures where alternative travel choices are provided (e.g. improved public transport, vanpooling, HOVs lanes) [3]. Another classification of policies includes hard measures such as road pricing, parking charges, new public transport service and soft measures such as workplace travel plans, personalized travel planning, public transport marketing and travel awareness campaigns [4].

Now-a-days, managing travel demand has widened the need of optimizing the performance of transportation system for commuting and non-commuting trips and for recurring and non-recurring congestion events [5]. TDM strategies that promote cheaper travel choices will be effective for a major portion of residents in developing countries [6]. TDM measures such as education and awareness campaigns, promotion of online or tele-working, support for ridesharing, public transport improvement and implementation of land use policies can reduce the vehicle trip. Introduction of parking restraints, and support for pedestrians and cyclists can also be effective in altering the travel pattern [7]. Imposing vehicle ownership taxes and other vehicle related taxes like road tax and parking charges may discourage both car ownership and usage [8]. The acceptability of a TDM measure is important to evaluate that whether a specific strategy will effectively change travel behaviour of commuters or not [9]. In different studies, push measures like road pricing and parking charges perceived low acceptance from public compared to pull measures like public transport improvement [10-11]. However, commuters normally perceive pull measures to be more suitable, even push measures often estimated to influence car use decrease largely [3, 12]. Moreover, the acceptability of a measure is important if its objective has to achieve [9, 13].

1.2 Scope and Objectives of Study

Lahore is the second largest city of Pakistan with population of almost 8.65 million and area about 1792 Km² [14]. The population has nearly doubled in last 20 years which represents 3% growth rate per annum [14]. It is believed that Lahore city has immense potential of mass transit development considering the number of trips generated due to high density development in the inner zone. Population density varies from 450 persons per hectare in the inner zone to 100 persons per hectare in the outer zone [14]. The 80% of population is almost living within a radius of 7-8 km from the city centre [14]. The rapidly growing population and traffic demand has resulted chronic traffic congestion on road network despite significant development. Number of vehicles is increasing at an alarming rate i.e. 17% per annum and major reasons of increase are the absence of an efficient public transport and government banking leasing policy for car ownership [14]. Other main factors in rapid increase of car ownership and usage are changing lifestyles, status symbol and low ownership and usage cost of automobile. Heavy traffic congestion on roads and the suffering of inhabitants from vehicle emissions demand alternative sustainable strategies to solve these problems. Vehicular traffic also threatens the pedestrian safety in busy urban areas [15]. The transportation policies are mostly developed just considering the benefits of automobile users, which impose greater external cost to most of the population. The fuel prices are increasing day by day and it is essential to focus on energy efficient transport. All these situations demand the consideration and implementation of demand side measures to solve congestion oriented problems, and ensure sustainability of the city.

It is believed that for successful implementation of demand management strategies, it is essential to
evaluate acceptability of specific policy measures. People’s behaviour can be a key issue in the success of any policy measure. In this context, stated preference approach can apply to evaluate the anticipated acceptability of TDM strategies before implementation [11]. Many studies in developed countries explore the influence of socio-economic demographics, situational factors and freedom in travel on acceptability of various TDM measures [2-3, 16-18]. In developing countries, only few studies provide the evidence of impact of socio-economic factors on acceptance and effectiveness of TDM measures [11, 19-20]. However, it is very important to explore significant factors in the acceptability of policy measures in specific region. Therefore, this study aims to analyze the commuter’s travel behaviour pattern, and their attitudes towards selected TDM measures. Initially, sample has been segmented into four classes based on vehicle ownership and modal share of this study, and a comparison was made among four segments for socio-economic features, and perceptions to TDM measures. Ordinal Logit models have been developed to analyze influence of socio-economic characteristics on perceptions to each TDM measure. This paper has been organized in the following manner. Section 2 describes the questionnaire design and survey methods. Distribution of socio-economic characteristics of respondents is presented in section 3. Commuters’ opinions to TDM strategies and results of ordinal logit modelling are discussed in section 4. Last section describes the conclusions and policy implications of this study.

2. DATA COLLECTION METHODS

2.1 Questionnaire Design

The findings of this study are based on results of a questionnaire survey. Seeking the objectives a questionnaire was designed consisting of two parts. Personal and travel information were asked in part one of questionnaire i.e. gender, age, income, education, occupation, vehicle ownership, trip frequency with different modes and for different trip purposes, possesses driving license or not, drive car and motorcycle or not. Travel pattern with different modes and for different trip purposes were asked using the following scale; never, a few times a year, a few times a month, 1-2 days a week, 3-4 days a week, and 5-7 days a week. In part 2 eight TDM strategies were selected seeking the feasibility of implementation in Lahore city, and presented in Table 3 with average response of respondents. The respondents were asked to give their opinion on each measure based on whether they support to a specific measure for reduction of traffic congestion or not. Carbon tax on gasoline only was included in case of fuel taxes considering the social impacts of tax on other fuels e.g. diesel, because increase in tax on diesel may result increase in prices of living goods. People’s willingness was also asked to pay road taxes for the improvements of traffic conditions, and support the increase in parking charges at office sites. The measures of willingness to do online or tele-work and participate in organization and institution based transport services were selected considering the current scenario and their future potential. Currently, some organizations and institutions are providing transport for their employees, and also provide home-based work for skilled workers. The inclusion of these measures would help in evaluating their future potential. The respondent’s willingness was asked for participation in traffic education and awareness programs, and use of public transport in case of better mode e.g. bus lanes or rapid rail mass transit. The respondent’s opinion was asked on provision of advance traffic information in order to alleviate traffic congestion. This questionnaire was designed to target current car users, and potential car users (current non car users). The rapid increase in car and motorcycle ownership as well as their usage in last ten years is the main reason of including opinions of potential car users. It was assumed that the attitudes of potential car users also needed to evaluate in advance towards TDM measures. In this study 4-point Likert scale was used to measure people’s response on stated questions of TDM measures. It was hypothesized that 4-point ordinal scale is appropriate considering a questionnaire survey in developing country and reliability of data in grasping the actual preferences. Therefore, 4-point scale was selected by seeking trade-off between simplicity of respondents in survey and data reliability.
2.2 Survey and Sampling

This questionnaire survey was conducted in Lahore during September 2011 with the help of university graduate students. The students were trained and instructed for the objectives of survey. Main target groups were students, employees of different private and government organizations and people related to commercial and business sector. The other main objective of this survey was to target daily commuters, and get mix of different mode users. Thirteen locations were selected in Lahore metropolitan area seeking the objectives of survey as presented in figure 1. The designed questionnaire initially was tested for concreteness and clarity through a pilot survey. Self-completion (by respondents) and interview approaches (interviews of respondents with the help of students) were used in survey deeming the literacy level of respondents. It was assured to conduct survey by interview from those respondents whose literacy level is low. The respondents were selected randomly at selected locations and total 1,000 questionnaires were used. The selected respondents were instructed about the contents of questionnaire and filling procedure to ensure the respondent understanding of
questionnaire items, and the reliability of collected data. Only 668 filled questionnaires were obtained which represented 66.8% return rate. Almost 300 samples were not returned by respondents even after three weeks as most of the questionnaires were distributed at various locations, and some questionnaire forms were wasted during the survey. Later on 37 samples were discarded from collected 668 due to incomplete information and double answers on some questions. Therefore, results of only 631 samples were used in analysis and ordinal modelling.

3. RESULTS AND DISCUSSION

3.1 Distribution of Socio-Economic Characteristics

3.1.1 Overall Distribution

The share of female respondents is only 23.3% percent of sample, which is quite less compared to total share of population. This is, because female do not drive motorcycle and bicycle, and do not work in commercial sectors (business, shops, etc.). The distribution of sample shows that 64.6% respondents have bachelor education or above, which is higher than the actual literacy rate in Lahore. It is due to presence of car and potential car users in large number in sample as they belong to medium to high household income category, and thus education level increases with the increase of household income. Sample represents a good mix of different mode users as well as occupations. The share of different modes in modal share follow as car (25.5%), motorcycle (35.5%), public transport [bus, wagon, Qingqi] (16.8%), auto-rickshaw/taxi (7.1%), office/school transport (5.9%), and walk/bicycle (9.2%). The share of students in sample is (23.6%), civil employees (20.8%), private employees (29%), entrepreneurs (15.7%), and others (11%). Collected samples nearly represent daily travelers in Lahore as 83.5% of respondents have trip frequency 5-7 days a week and 10.6% 3-4 days a week. Almost 33.3% respondents have car and 35.5% motorcycle driving license respectively. The respondents who drive vehicle asked for how they learned driving. Survey results show that 35.9% are self-trained, 52.7% learned driving from friends or family members and only 11.4% learned from a driving school. Almost 76.3% respondents were aged between 21-40 years. Average monthly household and personal income of respondents lies in 21,000-30,000 PKR and 10,000-15,000 PKR respectively.

3.1.2 Cross Distribution of Vehicle Ownership and Modal Share

A cross-analysis was conducted between modal share and vehicle ownership of this study. Initially, sample was segmented for vehicle ownership into four classes i.e. no vehicle, only motorcycle, car and motorcycle, and only car. The results of cross analysis as shown in Table 1 depict that those respondents who have car and motorcycle prefer to use private vehicle instead of other modes. From this analysis, four segments were identified based on mode dependency and captivity of choice. These segments include car oriented including auto-rickshaw and taxi users (204), motorcycle oriented (224), public transport oriented including office or school transport users (145) and non-motorized group or green travelers (58).

3.1.3 Cross Analysis of Personal Information with Four Segments of Mode Users

The results of cross-analysis for socio-economic characteristics among identified four segments as presented in Table 2 show that male are dominant in motorcycle oriented group and female in car and public transport oriented group. This is, because female do not drive motorcycle and just travel as passenger, and in case of car, they can drive and travel as a passenger. It can be argued that the travel behavior of female is dependent on male in motorcycle oriented group. The use of car increases with the increase of age, and motorcycle is dominant mode for age group of 21-30 years. The use of public transport decreases with increase of age. These results reveal that income increases as people approaches to higher age, and this results increase in auto ownership and usage. The dominance of motorcycle in age group of 21-30 years indicates that graduate students, and
fresh graduates and workers initially depend on motorcycle, and then with the increase of income approach towards car ownership and usage. The use of car is higher in small and motorcycle in large household. It is very realistic because household size decreases and car ownership increases with the increase of household income. The use of car again increases with the increase of education, whereas use of public transport decreases. This is, because education level in Lahore increases with the increase of household income which supports the findings of increase in car use with increase of education. Motorcycle group is dominant in middle income category. There is no significant variation among four groups for work or study trip. However, car and motorcycle oriented people travel more for shopping and recreational trips compared to public transport and non-motorized mode groups because later groups belong to low income category. This implies that these groups are very captive in mode choice and have low tendency for shopping and recreational trips. This may be due to expensive and inefficient public transport in the city.

3.2 Distribution of Respondents’ Socio-economic Characteristics

3.2.1 Average Rating of TDM Measures

A comparison was also conducted among four segments for average response to selected TDM measures. Advance traffic information measure has favorable evaluation from all groups. All groups have almost same intentions for participation in traffic education and awareness programs. Auto users have more favorable evaluation of tele-work strategy than non-auto users. It means these groups have more potential for such work because their education level is high and can easily get benefit of such opportunities. Public transport and car users have high positive evaluation of office or institution based transport service. It means that there is potential of providing office based transport service for employees and workers by targeting these specific people although the samples in non-motorized group are less. Car and motorcycle users have more willingness to use better mode of public transport such as bus lane or rail mass transit. Non-auto groups have less willingness because some of them may think that travel cost of these new modes would be high and it is difficult for them to avail this better opportunity. However, the potential of auto users can be utilized with the provision of state of the art public transport in order to make significant promotion from auto to public transport. Motorcycle users have low willingness for increase of parking charges for reduction of traffic congestion whereas car and public transport users have high willingness for increase of parking charges. Public transport and NMM users have low willingness to pay road taxes and carbon tax on gasoline. This is obvious because these groups belong to low income category, and they consider inflation and social impacts in evaluation of fiscal measures. All strategies have been ranked based on overall average response and average response of four segments and an optimal ranking has been proposed as presented in Table 4. The ranking places pull measures at the top (highly favorable measures) and push measures at the bottom (less favorable measures).

3.2.2 Ordinal Regression Analysis

Ordinal logit models were developed to examine the influence of respondent’s socio-economic characteristics on their response to selected TDM measures. Appropriate observed variables of personal and trip information were coded as 1, 0 for modeling purpose. Education, personal income gender, and existing travel mode were used as independent variables. Personal income is used as independent variable instead of household income because vehicle ownership and education are highly correlated with the household income. Similarly, regression parameters were estimated for male instead of female because share of female workers and female headed household is quite less in Lahore and they travel less compared to male. It has been supposed that implementation of any strategy is likely to have more influence on travel attitudes of male than female as they travel more. Therefore, response of male respondents is more critical and need to evaluate primarily. It was also assumed that estimation of regression parameters is important for different mode users in order to make some important implications for each group regarding different measures although rating has been proposed from average response. Regression analysis will also help statistically in evaluating the attitudes of current car users and potential car
**Table 1.** Distribution of modal share (frequent travel mode) across vehicle ownership.

<table>
<thead>
<tr>
<th>Vehicle ownership</th>
<th>Car AR/ taxi</th>
<th>MC</th>
<th>Office/school transport</th>
<th>Public bus</th>
<th>Public Wagon</th>
<th>Qingqi</th>
<th>Walk/Bicycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>No vehicle</td>
<td>0.0</td>
<td>6.59</td>
<td>2.20</td>
<td>7.69</td>
<td>29.67</td>
<td>14.29</td>
<td>13.19</td>
</tr>
<tr>
<td>Only MC</td>
<td>0.82</td>
<td>8.20</td>
<td>57.79</td>
<td>5.33</td>
<td>8.20</td>
<td>4.92</td>
<td>5.33</td>
</tr>
<tr>
<td>Car and MC</td>
<td>42.49</td>
<td>4.15</td>
<td>39.90</td>
<td>7.77</td>
<td>1.04</td>
<td>0.00</td>
<td>0.52</td>
</tr>
<tr>
<td>Only car</td>
<td>72.82</td>
<td>10.68</td>
<td>3.88</td>
<td>2.91</td>
<td>0.97</td>
<td>2.91</td>
<td>2.91</td>
</tr>
</tbody>
</table>

Note: AR: auto-rickshaw, MC: motorcycle, the above indexes are in %.

**Table 2.** Cross distribution of socio-economic features with four segments.

<table>
<thead>
<tr>
<th>Socio-demographics</th>
<th>Car oriented (%)</th>
<th>Motorcycle oriented (%)</th>
<th>Public transport oriented (%)</th>
<th>Non-motorized oriented (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>27.7</td>
<td>40.7</td>
<td>21.9</td>
<td>9.7</td>
</tr>
<tr>
<td>Female</td>
<td>47.6</td>
<td>18.4</td>
<td>26.5</td>
<td>7.5</td>
</tr>
<tr>
<td><strong>Age</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 20 years</td>
<td>33.0</td>
<td>22.0</td>
<td>36.3</td>
<td>8.8</td>
</tr>
<tr>
<td>21-30</td>
<td>27.6</td>
<td>43.4</td>
<td>20.0</td>
<td>9.0</td>
</tr>
<tr>
<td>31-40</td>
<td>42.9</td>
<td>27.0</td>
<td>26.2</td>
<td>4.0</td>
</tr>
<tr>
<td>&gt; 40 years</td>
<td>37.3</td>
<td>27.1</td>
<td>13.6</td>
<td>22.0</td>
</tr>
<tr>
<td><strong>Household members</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 5</td>
<td>39.3</td>
<td>29.4</td>
<td>24.3</td>
<td>7.0</td>
</tr>
<tr>
<td>&gt; 5</td>
<td>25.5</td>
<td>41.5</td>
<td>21.7</td>
<td>11.3</td>
</tr>
<tr>
<td><strong>Education</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Below bachelor</td>
<td>18.4</td>
<td>38.1</td>
<td>33.2</td>
<td>10.3</td>
</tr>
<tr>
<td>Bachelor &amp; above</td>
<td>40.0</td>
<td>24.1</td>
<td>17.4</td>
<td>8.6</td>
</tr>
<tr>
<td><strong>Personal Income</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low income</td>
<td>24.3</td>
<td>27.7</td>
<td>34.0</td>
<td>14.0</td>
</tr>
<tr>
<td>Middle income</td>
<td>21.9</td>
<td>48.6</td>
<td>22.7</td>
<td>6.9</td>
</tr>
<tr>
<td>High income</td>
<td>62.4</td>
<td>26.2</td>
<td>6.0</td>
<td>5.4</td>
</tr>
<tr>
<td><strong>Household income</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low income</td>
<td>12.6</td>
<td>29.9</td>
<td>37.8</td>
<td>19.7</td>
</tr>
<tr>
<td>Middle income</td>
<td>18.1</td>
<td>44.9</td>
<td>27.8</td>
<td>9.3</td>
</tr>
<tr>
<td>High income</td>
<td>51.7</td>
<td>30.9</td>
<td>12.8</td>
<td>4.5</td>
</tr>
<tr>
<td><strong>Work/study trip</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-7 days a week</td>
<td>32.1</td>
<td>35.6</td>
<td>21.8</td>
<td>10.3</td>
</tr>
<tr>
<td>3-4 days a week</td>
<td>31.1</td>
<td>41.9</td>
<td>24.3</td>
<td>2.7</td>
</tr>
<tr>
<td>1-2 days a week</td>
<td>31.4</td>
<td>37.1</td>
<td>22.9</td>
<td>8.6</td>
</tr>
<tr>
<td>A few times a month</td>
<td>37.5</td>
<td>34.4</td>
<td>18.4</td>
<td>9.4</td>
</tr>
<tr>
<td><strong>Shopping trip</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weekly</td>
<td>49.7</td>
<td>27.5</td>
<td>15.6</td>
<td>7.2</td>
</tr>
<tr>
<td>A few times a month</td>
<td>26.1</td>
<td>38.4</td>
<td>25.6</td>
<td>9.9</td>
</tr>
<tr>
<td><strong>Recreational trip</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weekly</td>
<td>43.4</td>
<td>32.4</td>
<td>17.6</td>
<td>6.6</td>
</tr>
<tr>
<td>A few times a month</td>
<td>29.3</td>
<td>36.4</td>
<td>24.4</td>
<td>9.9</td>
</tr>
</tbody>
</table>
users (e.g. current motorcycle and public transport users) towards TDM measures. Moreover, multi-
collinearity was checked among independent variable, values of variance inflation factor (VIF) found on lower side i.e. less than 3.0. In the field of statistics, it is believed that the multi-collinearity among independent variables does not exist if VIF values are less than 5 or even 10 [21-22]. The detail of explanatory variables and modeling results is given in Table 5. Parameters for traffic education and awareness measure were not presented here because model estimation did not find any significant model and parameter values. The estimated values of $\rho^2$ are found to be on lower sides which show low reliability of models. However, some important implications can be made from significant explanatory variables for each policy measure.

3.2.2.1 Advance traffic information: Modeling results for this measure show that gender, education, and personal income have significant impact on commuter’s perceptions to advance traffic information. The male respondents have positive attitudes towards this measure because they travel more and provision of advance traffic information would help in making their trips efficient. Increase in education and personal income result positive attitudes towards this measure. It means people who have high education feel that this measure would be appropriate to alleviate traffic congestion. It would be easy for such class of people to get latest information using different sources such as mobile phone, internet, and variable message signs. However, affordability of sources to get information, and readability of text information are key issues associated with low income and low educated people.

3.2.2.2 Tele-work: The respondent’s education is the only significant explanatory variable in the model of tele-work strategy. The respondents with higher education have positive attitudes towards acceptance of this measure. This is, because highly educated people have more awareness about such works, and potential to do compare to low educated people. This potential can be utilized for reduction of private vehicle trips, because one main reason of using private vehicle is the part-time work or side business. If skilled and highly educated people can get such part time opportunity through online working programs then it would help in reducing the use of private vehicle. Car and public transport users have negative attitudes towards this strategy whereas motorcycle users have positive propensity. It means middle income people with higher education should be the target group of this policy because motorcycle users mainly belong to middle income category such as fresh graduates and age group of 21-30 years. Moreover, trend of doing part-time work is more in middle income group, and provision of this policy would help them in reducing the travel of private vehicle.

3.2.2.3 Office based transports service: The respondent’s education, income and variable of public transport users are significant determinants of people’s attitudes towards office based transport policy. Education and income have positive association with respondent’s participation in transport service from organizations or institutions. Public transport users also have positive attitudes towards this service because they belong to low to middle income category and this service will be cheaper as compare to public transport. The male respondents, car and motorcycle dependent people have negative attitudes towards transport service which indicates high auto dependency. Inflexibility, lengthy route and fix schedule are the main reasons of not using this service.

3.2.2.4 Public transport improvement: The gender is the only significant variable in the model of public transport improvement. It shows that male have more potential of using improved public transport than female because in some families female are not allowed to travel on public transport especially in high income group. In some cases female can travel on public transport but only with male members. Higher education level decreases the potential of public transport usage because education level and car ownership increases with the increase of household income. Therefore, highly educated people do not prefer to travel on public transport because they may think that it does not reflect their status and respect in the society. However, current car and motorcycle users have positive attitudes towards bus lane or rapid rail mass transit system. It can be argued that some people may use improved public transport for daily commuting, as it is reliable from private transport. However, travelling with
Table 3. Average rating of TDM measures from different groups.

<table>
<thead>
<tr>
<th>TDM Measures</th>
<th>Car</th>
<th>MC</th>
<th>PT</th>
<th>NMM</th>
<th>OA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advance traffic information would be very helpful to relieve traffic congestion</td>
<td>3.43</td>
<td>3.40</td>
<td>3.31</td>
<td>3.38</td>
<td>3.36</td>
</tr>
<tr>
<td>I have intention to participate in traffic education and awareness programs</td>
<td>2.94</td>
<td>2.96</td>
<td>3.01</td>
<td>2.95</td>
<td>2.96</td>
</tr>
<tr>
<td>I have intentions to do online or tele-working if there will be an opportunity</td>
<td>2.84</td>
<td>2.79</td>
<td>2.65</td>
<td>2.71</td>
<td>2.75</td>
</tr>
<tr>
<td>I have intention to participate in office based transport service from organization/institutions</td>
<td>2.70</td>
<td>2.47</td>
<td>2.64</td>
<td>2.55</td>
<td>2.59</td>
</tr>
<tr>
<td>I would use public transport if there is better mode like rapid rail mass transit or bus lanes</td>
<td>3.23</td>
<td>3.30</td>
<td>3.13</td>
<td>2.90</td>
<td>3.20</td>
</tr>
<tr>
<td>I support to increase parking charges in order to reduce traffic congestion in the city</td>
<td>2.38</td>
<td>2.20</td>
<td>2.31</td>
<td>2.27</td>
<td>2.29</td>
</tr>
<tr>
<td>I support to put more carbon tax on gasoline in order to protect environment</td>
<td>2.68</td>
<td>2.57</td>
<td>2.40</td>
<td>2.45</td>
<td>2.52</td>
</tr>
<tr>
<td>I would pay more road taxes in order to improve traffic conditions in the city</td>
<td>2.83</td>
<td>2.74</td>
<td>2.56</td>
<td>2.57</td>
<td>2.71</td>
</tr>
</tbody>
</table>

Note: MC: motorcycle, PT: public transport, NMM: Non-motorized modes, OA: overall

Table 4. Ranking of TDM measures.

<table>
<thead>
<tr>
<th>TDM Measures</th>
<th>Overall</th>
<th>Car</th>
<th>Motorcycle</th>
<th>Public transport</th>
<th>Non motorized</th>
<th>Optimal ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advance traffic information</td>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
</tr>
<tr>
<td>Public transport improvement</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
</tr>
<tr>
<td>Education &amp; awareness programs</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
</tr>
<tr>
<td>Tele-work</td>
<td>4&lt;sup&gt;th&lt;/sup&gt;</td>
<td>4&lt;sup&gt;th&lt;/sup&gt;</td>
<td>4&lt;sup&gt;th&lt;/sup&gt;</td>
<td>4&lt;sup&gt;th&lt;/sup&gt;</td>
<td>4&lt;sup&gt;th&lt;/sup&gt;</td>
<td>4&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td>Road tax</td>
<td>5&lt;sup&gt;th&lt;/sup&gt;</td>
<td>5&lt;sup&gt;th&lt;/sup&gt;</td>
<td>5&lt;sup&gt;th&lt;/sup&gt;</td>
<td>6&lt;sup&gt;th&lt;/sup&gt;</td>
<td>5&lt;sup&gt;th&lt;/sup&gt;</td>
<td>5&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td>Office based transport service</td>
<td>6&lt;sup&gt;th&lt;/sup&gt;</td>
<td>6&lt;sup&gt;th&lt;/sup&gt;</td>
<td>7&lt;sup&gt;th&lt;/sup&gt;</td>
<td>5&lt;sup&gt;th&lt;/sup&gt;</td>
<td>6&lt;sup&gt;th&lt;/sup&gt;</td>
<td>6&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td>Carbon tax on gasoline</td>
<td>7&lt;sup&gt;th&lt;/sup&gt;</td>
<td>7&lt;sup&gt;th&lt;/sup&gt;</td>
<td>6&lt;sup&gt;th&lt;/sup&gt;</td>
<td>7&lt;sup&gt;th&lt;/sup&gt;</td>
<td>7&lt;sup&gt;th&lt;/sup&gt;</td>
<td>7&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td>Parking charges</td>
<td>8&lt;sup&gt;th&lt;/sup&gt;</td>
<td>8&lt;sup&gt;th&lt;/sup&gt;</td>
<td>8&lt;sup&gt;th&lt;/sup&gt;</td>
<td>8&lt;sup&gt;th&lt;/sup&gt;</td>
<td>8&lt;sup&gt;th&lt;/sup&gt;</td>
<td>8&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

female family members may prefer to use private vehicle because of privacy and other situational factors e.g. shopping, emergency, travelling at night, and service quality factors of public transport e.g. no direct access to some destination, fixed and limited schedule, etc. Positive relation of current public transport users with this strategy implies that improved service would help in keeping existing users.

3.2.2.5 Parking charges: The gender and education are only significant explanatory variables for this measure. The male respondents have negative attitudes towards increase in parking charges, whereas higher education results positive attitudes towards this policy. It means high income people have more potential for acceptance of this policy such as car users, and there is potential of increase in parking charges on car use as mostly car users belong to high income category. This would help in collecting revenues which can be used for the improvement of road infrastructure especially public transport system although it may not have significant influence on travel behavior of car users. Motorcycle and public transport users have negative attitudes towards acceptance of increase in parking charges. This is due to low income of these groups
compared to car users because increase in parking charges would put extra burden on their income.

3.2.2.6 Carbon tax on gasoline: The modeling results reveal that education is the only significant variable and it has positive relationship with this strategy. It means people having high education have more value of environment, and aware well about the negative consequences of fuel consumption. Therefore, they have more willingness to pay carbon tax on gasoline for reduction of air pollution. Similarly, high income people and current car users have positive perceptions towards increase in carbon tax on gasoline. However, low and middle income people have low willingness to pay carbon tax on gasoline as public transport and motorcycle users. This is due to social impacts of increase in taxes on gasoline because such increase always cause inflation and put additional burden on low and middle income people. It is suggested that social impacts must be considered in increasing taxes on gasoline, and differential type fuel pricing can be adopted in order to reduce these impacts. The imposition of this tax would also help in reducing air pollution.

3.2.2.7 Road tax: In this model, only variables of education and public transport users are significant. Highly educated people have positive attitudes towards increase in road tax for improvement of traffic conditions in the city. It means that highly educated people have more awareness about traffic

### Table 5. Results of ordinal logit modeling.

<table>
<thead>
<tr>
<th>Explanatory variable</th>
<th>Advance traffic information</th>
<th>Tele-work</th>
<th>Office based transport</th>
<th>Public transport improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PV</td>
<td>t-value</td>
<td>PV</td>
<td>t-value</td>
</tr>
<tr>
<td>Gender</td>
<td>.603</td>
<td>-2.346</td>
<td>.043</td>
<td>.632</td>
</tr>
<tr>
<td>Education</td>
<td>.499</td>
<td>-2.738</td>
<td>.417</td>
<td>-2.633</td>
</tr>
<tr>
<td>Personal income</td>
<td>.002</td>
<td>-1.676</td>
<td>.068</td>
<td>-1.027</td>
</tr>
<tr>
<td>Car users</td>
<td>-.021</td>
<td>-1.504</td>
<td>-.197</td>
<td>-4.67</td>
</tr>
<tr>
<td>Motorcycle users</td>
<td>-.293</td>
<td>.847</td>
<td>.369</td>
<td>.526</td>
</tr>
<tr>
<td>Public transport users</td>
<td>.079</td>
<td>-1.299</td>
<td>-.075</td>
<td>-3.07</td>
</tr>
</tbody>
</table>

**Output statistics**

- \( L(0) \) = -425.42, -520.87, -518.65, -445.10
- \( L(\beta) \) = -410.57, -511.04, -511.83, -436.33
- \( \hat{\rho}^2 \) = 0.035, 0.018, 0.019

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parking charges</th>
<th>Carbon tax on gasoline</th>
<th>Road tax</th>
<th>Explanatory variables</th>
</tr>
</thead>
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<td></td>
<td>PV</td>
<td>t-value</td>
<td>PV</td>
<td>t-value</td>
</tr>
<tr>
<td>Gender</td>
<td>-.284</td>
<td>2.554</td>
<td>-.066</td>
<td>.904</td>
</tr>
<tr>
<td>Education</td>
<td>.380</td>
<td>2.587</td>
<td>.281</td>
<td>-.1971</td>
</tr>
<tr>
<td>Personal income</td>
<td>.095</td>
<td>-.687</td>
<td>.125</td>
<td>-.931</td>
</tr>
<tr>
<td>Car users</td>
<td>-.120</td>
<td>-1.120</td>
<td>.078</td>
<td>-.446</td>
</tr>
<tr>
<td>Motorcycle users</td>
<td>-.246</td>
<td>1.079</td>
<td>-.144</td>
<td>-.296</td>
</tr>
<tr>
<td>Public transport users</td>
<td>-.350</td>
<td>-1.042</td>
<td>-.200</td>
<td>-.1180</td>
</tr>
</tbody>
</table>

**Output statistics**

- \( L(0) \) = -499.83, -521.06, -514.71
- \( L(\beta) \) = -490.21, -504.81, -504.78
- \( \hat{\rho}^2 \) = 0.020, 0.031, 0.021

**Note**: PV: Parameter value; \( \hat{\rho}^2 \) = 1-\( \frac{L(\beta)}{L(0)} \)
situation in Lahore as they travel more. Car users also have positive attitudes towards willingness to pay road tax where as motorcycle and public transport users have negative attitudes. This is, because car users mainly belong to high income category, and public transport and motorcycle users belong to low to middle income class respectively. It implies that car oriented class is willing to pay taxes in order to have better road infrastructure, and use congestion free roads. Therefore, this potential can be utilized for collection of revenue for the improvement of traffic conditions in city by targeting this specific group. Collected revenues can also be used for the improvement of public transport system in order to keep existing users and to attract auto users for proper modal shift.

4. CONCLUSIONS AND IMPLICATIONS
This paper focuses on evaluation of travel pattern, and relationship among respondent’s socio-economic characteristics and attitudes towards selected TDM measures. Initially, cross analysis among vehicle ownership and modal share identifies four segments i.e. car oriented, motorcycle oriented, public transport oriented and non-motorized mode oriented. A comparison was made among four segments for SEDs and perception to TDM measures. The cross analysis depict that public transport and non-motorized modes are modes of low income people, and motorcycle is dominant mode in middle income group. Public transport and non-motorized modes are modes of poor people, and these people have low tendency for shopping and recreational trips. This analysis further identifies two types of travel behavior i.e. auto-dependent behavior of people who have private vehicle, and captive behavior of people who do not have private vehicle. The perceptions to TDM strategies among four segments also vary. The acceptance level for fiscal measures is lower compared to other measures. However, acceptance level can be enhanced by highlighting the benefits to the public associated with implementation of each measure through social marketing and awareness programs.

The results of ordinal modeling reveal that education is the highly significant explanatory variable in determining the people’s attitude towards most of the policy measures. Higher education tends to enhance people’s awareness about the traffic conditions, and consequences of their own behavior. In return, this results higher acceptance of different strategies. Gender, income and existing travel mode are also significant determinants of specific policy measures. These variables related differently (positively or negatively) with different TDM measures. Survey and modeling results reveal that there is potential for promotion of tele-work and office based transport policies in Lahore for specific segment of travel market. Improvements in public transport would help in making promotion from private vehicle to public transport as auto users have positive attitudes towards this strategy. In addition, imposition of fiscal measures such as fuel and road taxes on car use would help in restricting the potential car users on their existing mode, and collection of revenues from car users that can be used to improve the road infrastructure and public transportation. Optimal ranking was proposed based on average response from all groups of respondents. The provision of advance traffic information is ranked as first, public transport second, traffic education and awareness programs third, tele-work forth, willingness to pay road tax fifth, organization based transport service sixth, carbon tax on gasoline seventh and increase in parking charges eighth. This ranking implies that incentive or pull measures need to initiate first which should be followed by push or disincentives measures. In addition, theoretically it can be suggested that integration among pull and push measures is much important in implementation because any strategy alone cannot be effective in changing the travel behavior [2, 23–24] although combination of measures are not considered in this study. For example, public transport improvement should be integrated with parking control measures such as imposition of parking charges in commercial as well as in public transport service area. Imposition of car usage related taxes (fuel taxes, road taxes) could also help in reducing transport sector externalities. Similarly, education and awareness programs need to initiate in conjunction with strict implementation of traffic rules. This study recommends determining the desire service quality of each segment especially auto users, and suggests the improvement in public transport accordingly. The assurance of good quality public transport would help to keep existing users,
and attract auto users.

Fig. 2 explains the process of consideration of TDM measures for implementation in Lahore city as well as similar cities of other developing countries. It is suggested that advance traffic information, education and awareness programs need to introduce in combination because traffic information system or media can also be used to educate the people about transportation problems and their effective solutions. These measures should be followed by trip reduction measures such as public transport improvement, tele-work opportunities and office based transport service. Finally, fiscal restrictions should be imposed on car use i.e. parking charges, fuel tax on gasoline and other car usage taxes in order to enhance the effectiveness of trip reduction measures. This study would provide a clear understanding of travel behavior pattern of people having different socio-economic characteristics to transport planners and policy makers for making appropriate set of TDM policies in order to change travel behavior, and reduce auto-dependency. However, proper attention is required in selection combinations of different measures. Future studies need to focus on evaluation of packages of TDM measure as combined measures are more effective in changing travel behavior. In addition, attitudinal and behavioral aspects of travellers also need to consider in evaluating the packages of measures.

5. ACKNOWLEDGEMENTS

The authors acknowledge the financial support of “Engineering Management Program of Graduate School of Engineering, Yokohama National University, Japan” and “Ministry of Environment, Japan” for field trip to Lahore, Pakistan. The authors also acknowledge the cooperation of Department of Transportation Engineering and Management, University of Engineering and Technology, Lahore in conducting the questionnaire survey.

6. REFERENCES

Travel Demand Management Measures in Lahore


Power Draw, Solid Suspension and Liquid Mixing in a Non-standard Stirred Tank Reactor fitted with a Retreat Curve Impeller

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Abstract: The pharmaceutical sector often uses non-standard impellers and stirred tank reactor (STR) geometries, compared to those in other chemical processes. Many such reactors are glass-lined to provide corrosion prevention and to avoid product contamination. Typically, these contain retreat curve impellers, which may have been modified to fit into a conical-based vessel, designed for ease of product discharge. These geometries are not covered by the standard correlations in the literature. This research work was carried out using a conical-based vessel with a diameter of 0.29 m. Power numbers have been obtained for a range of impeller clearances and baffling arrangements and correction factors have been proposed to account for the effect of the conical base and partial baffles. Liquid blending operations have been shown to occur rather quickly in the vessel mainly due to the use of impeller with increased diameter. Just-suspended impeller speeds for solids dispersion have been measured and correlated with Zwietering’s equation. The values of Zwietering’s $s$ parameter are proposed for a range of liquid fill levels, impeller clearances and baffle arrangements.

Keywords: Pharmaceuticals, stirred tank reactor, solid-liquid mixing, power number, mixing time

1. INTRODUCTION

Stirred tank reactors (STRs) are widely used throughout the pharmaceutical sector for mixing, heat and mass transfer, chemical reaction and crystallization. The design of these tanks is often based on empirical design equations, scale-up rules and heuristics derived from experiments conducted in so-called standard geometry vessels, similar to those used in petrochemical and fine chemicals processing [1]. In these industries, cleaning and emptying of vessels is not an issue, and so the standard designs are usually based around small diameter impellers (e.g. pitched blade turbines and commercial hydrofoils) operating in turbulent flow conditions, with four wall baffles, dished bases and fill heights of around one tank diameter. In contrast, many mixing and reaction vessels in the pharmaceuticals sector are glass-lined and have partial or no baffling; they may use non-standard impellers, such as the retreat curve impeller (RCI) [2]. Furthermore, many such vessels feature conical bases, which are intended for ease of product
discharge, and may be operated at relatively low fill levels; the RCI designs are often modified to match the conical base, e.g. by angling the blades upwards [3].

A large proportion of pharmaceutical STRs are used for solid-liquid processing operations [4]. For example, mixing, reaction and heat transfer are commonly used to nucleate a crystal phase; the distribution of super-saturation and the processes of nucleation, crystal growth, agglomeration and crystal breakage are all partly affected by the hydrodynamic environment. Consequently, mixing can affect the crystal size distribution and morphology, as well as the homogeneity of a solids suspension withdrawn from the vessel. These properties can adversely affect downstream separation processes, such as filtration, isolation and drying. Thus they partly determine the overall yield of the process and the characteristics of the final product. The work described here is a first-step towards understanding these complex issues, by characterizing the liquid and solid-liquid flows in conical-based vessels.

2. EXPERIMENTAL
The experimental rig is schematically shown in Fig. 1, where diameter \( D = 0.18 \) m, 3-bladed retreat curve impeller in a transparent conical base STR of \( T = 0.29 \) m as inside diameter. The maximum vessel volume was 20 L, fill levels corresponding to \( H/T = 0.50, 0.75 \) and 1.00 were investigated, as well as various clearances of the impeller above the base of the cone. The conical base STR was surrounded by a square tank filled with water to provide an undistorted view of the vessel contents. Observations were used for flow visualization (Fig. 2) using neutrally buoyant 0.5 mm particles and to find just suspended speeds for solid suspension. Within the tank, between 1 and 4 wall baffles could be installed; these were 0.03 m wide and 0.005 m thick baffles and were equally spaced in the tangential direction. Alternatively, a single 0.03 m wide beavertail baffle with a thickness of 0.01 m could be positioned in the STR at \( 0.44T \) from the bottom and at \( 0.17T \) from the vessel wall. The vessel headspace was open to the atmosphere and the working fluid used in all the experiments was tap water.

The power input was calculated from the torque on the impeller shaft which was measured by a Torque Track 9000 digital telemetry system (Binsfeld Engineering Inc.); strain gauges and an FM transmitter were mounted on the impeller shaft and the signals were received by a wireless antenna. The strain gauges were below the top bearing on the shaft so no frictional effects were measured. Preliminary checks measured the power numbers of standard geometry impellers such as the Rushton turbine (6DT) and the pitched blade turbine (PBT) in flat-based vessels, which agreed well with the values reported in the literature [5].

The mixing time experiments were performed by measuring the concentration time history of a salt (NaCl) tracer; the effects of different geometric arrangements were studied. A 50 ml salt solution containing about 1 mass % NaCl was introduced at the top surface of the vessel. A single conductivity probe with a tip diameter of about 1 mm [6] was placed near the discharge of the impeller and was connected to the conductivity meter, which sent a voltage to a PC data logger at 12 Hz. 95% mixing time was calculated as the time required for the concentration fluctuations to have decayed within ±5% of the well-mixed value. It was found that consistent average values could be obtained by repeating the mixing time experiments three times for each experimental condition.

Glass ballotini particles with a density of 2500 kg/m³ were used in the solids suspension experiments and the weight fraction was varied from 2 to 30 mass %. Two particle sizes were used, with weight-average diameters of 220 and 540 μm; these had fairly narrow size distributions with standard deviations of 55 and 85 μm, respectively. Zwietering's [7] just-suspension criterion was applied to obtain \( N_{js} \), i.e., it was considered that complete suspension of solids had occurred when no particle remained on the bottom of the tank for more than 1–2 sec, as observed by visual inspection.

3. RESULTS AND DISCUSSION

3.1 Flow Visualizations
Neither the wall baffles nor the beavertail baffle
Fig. 1. The geometry of the conical vessel, retreat curve impeller and baffles used in the experimental work.

Fig. 2. Flow visualization performed in the conical vessel with a retreat curve impeller and a single wall baffle (located behind the impeller shaft).

Fig. 3. RCI power numbers with 1 or 4 wall baffles and at two clearances; comparison of flat and conical bottoms.
extend into the conical section (Fig. 1) and hence the flow in that region is effectively unbaffled. As a consequence the liquid velocity is predominantly tangential. Above the conical section, even with a single baffle the tangential flow is disrupted and converted into axial and radial components. With a single baffle, the flow structure is difficult to determine from instantaneous snapshots, but Li et al.’s [8, 9] CFD simulations suggest that there ought to be a down-flow around the shaft and an up-flow at the walls, with weak flows near the surface, which is in agreement with Fig. 2 depiction. Streak photographs, such as shown in Fig. 2, were obtained for a number of baffle configurations for the RCI. Surprisingly, the case with four wall baffles produced a rather chaotic flow above the conical section, with some segregation from the flow in the cone below.

3.2 Power Input of the RCI

Power inputs were measured for a range of mixer configurations, over Reynolds numbers in the turbulent regime (\( Re = \rho ND^3/\mu > 10^4 \)). The effects of conical bases, partial baffles (1 or 4 wall baffles or a beavertail baffle) and various impeller clearances on the power number were investigated and are presented in Fig. 3, 4. Campolo et al. [10, 11] reported measured power numbers, \( P_0 \), for a \( D/T = 0.58 \), three-bladed RCI and for two beavertail baffles. In their laboratory scale apparatus \( (T = 0.31 \text{ m}) \) the power number fell from 0.79 to 0.70 over the range \( 10^4 < Re < 10^5 \), although their calculation from Nagata’s [12] correlation suggested that it should remain constant. Dickey et al. [13] found only a small decrease in \( P_0 \) in this Reynolds number range for a 0.17 width finger baffle. Li et al. [8, 9] calculated power numbers for an RCI with a single cylindrical baffle, but found no effect of Reynolds number in the range \( Re > 10^4 \). Therefore, for systems containing partial baffling it was expected that \( P_0 \) would be approximately independent of Reynolds number in the range studied \( (Re > 4\times10^4) \), which is what is shown in Fig. 3, 4, where there is only a very small effect of the impeller clearance, which is in agreement with Nagata’s [12] power number correlation.

Averaged power numbers are presented in Table 1: at the lowest clearance of \( C/T = 0.16 \), the power number is less than 10% greater than for the more standard clearance of \( C/T = 0.31 \), for the flat-based vessel. The effect is slightly greater for the conical-based vessel, since the shape of the blades is such that their tips come very close to the tank base at the lowest clearance studied here. Table 1 and Fig. 3 show that conical-based vessels generally draw less power than the flat-based systems, with

\[
\left( \frac{P_0}{P_0} \right)_{\text{conical}} / \left( \frac{P_0}{P_0} \right)_{\text{flat}} \approx 0.89 \pm 0.06
\]

for all baffle types and clearances and also for a 6DT operated in these two vessels (Table 1). Equation (1) represents the power number correction factor when only the vessel base shape has changed and all other geometric variables remain fixed. The predominant effect in Fig. 3, 4 is of changing the number of baffles. Compared to the fully baffled (4 wall) cases, the power numbers are given approximately by:

\[
\left( \frac{P_0}{P_0} \right)_1 / \left( \frac{P_0}{P_0} \right)_4 \approx 0.55 \pm 0.04
\]

and

\[
\left( \frac{P_0}{P_0} \right)_h / \left( \frac{P_0}{P_0} \right)_4 \approx 0.43 \pm 0.03
\]

Table 1. Averaged power numbers over the range \( 4\times10^4 < Re < 2\times10^5 \) (turbulent flow) for the retreat curve impeller (RCI) and 6 bladed disk turbine (6DT) in flat and conical-based vessels.

<table>
<thead>
<tr>
<th>Impeller Bottom</th>
<th>RCI flat</th>
<th>RCI conical</th>
<th>RCI flat</th>
<th>RCI conical</th>
<th>6DT flat</th>
<th>6DT conical</th>
<th>6DT flat</th>
<th>6DT conical</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C/T )</td>
<td>0.16</td>
<td>0.16</td>
<td>0.31</td>
<td>0.31</td>
<td>0.16</td>
<td>0.16</td>
<td>0.31</td>
<td>0.31</td>
</tr>
<tr>
<td>4 wall baffles</td>
<td>0.80</td>
<td>0.71</td>
<td>0.75</td>
<td>0.71</td>
<td>5.41</td>
<td>5.06</td>
<td>5.22</td>
<td>4.83</td>
</tr>
<tr>
<td>1 wall baffle</td>
<td>0.44</td>
<td>0.41</td>
<td>0.44</td>
<td>0.35</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>1 Beavertail baffle</td>
<td>0.36</td>
<td>0.33</td>
<td>0.33</td>
<td>0.27</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>
for the single wall (1w) and beavertail (1b) baffles, respectively. Here, \((P_{0})_{dw}\) is the power number for the same geometry of impeller and vessel, but with 4 wall baffles. Thus eq. (1) represents the power number correction factor when only the number of baffles has changed and all other geometric variables remain fixed. Myers et al. [14] indicated that changing from 4 to 1 wall baffles resulted in about a 60% decrease in power draw for a radial pumping impeller, which is similar to the power number correction factor given in eq.(2).

3.3 Mixing Time Measurements with RCI in a Conical-based Vessel

Before commencing work with the RCI, some preliminary results were obtained to compare the 95% mixing times of a standard geometry PBT down-pumping impeller [15] in flat- and conical-based vessels. The measurements in Fig. 5 followed a curve given by \(N\theta_{95} = \text{constant}\), as suggested by Ruskowski’s [16] generalized correlation shown in eq.(4) below:

\[
N\theta_{95} = \frac{5.3}{P_{0}^{1/3}} \left( \frac{T}{D} \right)^{2}
\]  

(4)

For the PBT in a flat-based vessel \((P_{0} = 1.3 [15]\) and \(D/T = 1/3\), eq. (4) predicts a dimensionless mixing time of 44, which agrees well with the experimental measurements shown in Fig. 5. In the conical-based vessel, the measured dimensionless mixing times were about 50% lower and there was no effect of impeller clearance, at the two values investigated. Ruskowski’s [16] correlation may also be written as

\[
\theta_{95} = 5.91 \left( \frac{\rho V}{P} \right)^{1/3} \left( \frac{T}{D} \right)^{1/3} T^{2/3}
\]  

(5)

In changing from a flat to a conical base, eq. (1) indicates that there should only be a small reduction in power input for the PBT for a given impeller speed. The volume contained at \(H = T\) in the conical-based vessel is 12.8 L (compared to 19.2 L for the flat-based vessel), but eq. (5) shows that this effect is not large enough to account for the 50% reduction in mixing time shown in Fig. 5. It would appear that the down flows generated by the PBT are significantly changed when the impeller is placed at low clearance in a conical-based vessel.

Mixing times were also measured with the RCI in the conical-based vessel at a number of impeller clearances and with various baffle arrangements, as shown in Fig. 6–8. Dye tracer and flow visualization experiments indicated that for \(Re > 10^4\) there were no dead zones with any of the baffling arrangements used. Repeated measurements of the mixing time varied by about 10% either side of the mean, but generally the results agreed with the form \(N\theta_{95} = \text{constant}\).

In the conical-based vessel, the differences in dimensionless mixing times for 1, 2, 3 and 4 wall baffles were small (e.g., varying between 6.9 and 8.7; Fig. 6, 9). Of all the wall baffle arrangements, the four baffle case gave the longest mixing times, despite the fact that this configuration had the largest power input for a given impeller speed. The shortest mixing times were for a single wall baffle, although at the highest clearance \((C/T = 0.31)\) all four wall baffle arrangements had approximately the same value of \(N\theta_{95}\) (Fig. 9). Myers et al. [14] reported only minor differences in blend times for mixed, axial and radial discharge impellers for between 1 and 4 wall baffles, with a weak minimum for 2 baffles. Other workers have reported small decreases in the mixing time on increasing the number of wall baffles from 2 to 6 [17]. Fig. 9 shows the longest mixing times were for the single beavertail baffle, which produced strong components of radial and axial flow above the conical section, but did little to disrupt the swirling flow below. Thus the single beavertail is the least effective for liquid blending; the difference is greatest at the highest clearance of \(C/T = 0.31\). However, all the configurations studied here had relatively short dimensionless mixing times and it may be concluded that partial baffling and conical-bases are unlikely to lead to severe blending problems in these high Reynolds number flows.

Equation (4) shows that an increase in \(D/T\) results in a significant decrease in the dimensionless mixing time, which is one reason why the RCI remains effective at liquid blending, despite the reduced baffling arrangements. For a flat-based vessel, eq. (4) predicts \(N\theta_{95} = 14.8\), whereas Fig. 6 shows that the measurements are about \(N\theta_{95} = 9.2\).
Fig. 4. RCI power numbers with a single beavertail baffle and at two clearances; comparison of flat and conical bottoms.

Fig. 5. The effect of vessel base shape on the 95% mixing time for a PBT with four wall baffles.
Thus eq. (4) provides a conservative estimate of the mixing time. For four wall baffles, the difference between the mixing times in the flat and conical-based vessels is small, with the latter giving about 5% lower $N_{θ95}$ values (Fig. 6). This difference is smaller than is shown in Fig. 5, which may indicate that the axial / mixed discharge flow of the PBT is much more affected by the presence of the conical base than the more radial discharge of the RCI. The conclusion from the data obtained with the PBT and the RCI is that the effect on the mixing time, of changing from a flat- to a conical-based vessel, cannot be taken into account using a simple correction factor which is a constant for all impeller types.

### 3.4 Just-suspended Conditions for RCI in a Conical-based Vessel

Visual observations showed that solids accumulation in the apex of the conical base was a severe problem and that large values of $N_{js}$ were frequently obtained; in many configurations the solids could not be suspended at the maximum motor speed of 410 rpm. In some cases the particles became suspended in the conical section, but the axial circulation generated in the baffled upper section appeared to prevent solids being distributed higher in the vessel. Fig. 10 shows the effect of baffling and impeller clearance on the just-suspended speed for 10 mass % of 220 $\mu$m diameter solids at liquid heights of $H = 0.75 T$ and $H = T$. The values of $N_{js}$ are significantly affected by the impeller clearance, but in contrast to conventional dished-based vessels, they are also a function of the liquid height. The lower part of the vessel is essentially unbaffled since the baffles terminate where the cone meets the straight section of wall (Fig. 1). Fig. 2 shows that there is a strongly swirling flow in the apex of the cone, which is not affected by baffling and as a consequence particle suspension is adversely affected. As the impeller clearance is increased, the discharge flows impinge on the wall baffles and stronger axial and radial liquid circulations are obtained, but these do not penetrate deep into the cone. Hence, $N_{js}$ increases with an increase in $C/T$. At clearances of $C / T > 0.3$ and $H / T = 0.75$, the value of $N_{js}$ exceeded the top speed of the motor and hence the solids could not be fully suspended. At $H / T = 0.50$ the baffles were hardly immersed and $N_{js}$ often exceeded the maximum speed of the motor so that few data were obtained. For liquid heights of $H = 0.75 T$ and $H = T$, the tank configurations with four baffles gave the worst (highest) solids suspension speeds and those with a single wall baffle or a single beavertail were the best arrangements. Single baffles led to an asymmetric flow pattern which appeared to be better at picking up solids from the apex of the cone.

Similar results were obtained with the larger 540 $\mu$m particles, as shown in Fig. 11 for a single wall baffle. Other wall baffling arrangements were also studied, but the only results that could be obtained were for very low solids fractions and low clearances. With increasing impeller clearance or with lower liquid levels, the particles became harder to suspend. Zwietering [7] conducted a wide range of experiments on the just-suspended speeds for solids and proposed the following dimensionless correlation.

$$N_{js} = s \sqrt{\frac{g \Delta \rho}{\rho_L}} 0.45 X^{0.13} d_p^{0.2} D^{-0.85}$$  \hspace{1cm} (6)

Habib [18] correlated $N_{js}$ against the % solids mass ratio $X$ and found exponents ranging from 0.05 to 0.15, which were broadly in agreement with eq. (6). Table 2 contains Zwietering’s values fitted to the data for the various geometries investigated in the current work by assuming that the form of eq. (6) applies to the RCI in a conical-based vessel. Generally these $s$ values increase with increasing clearance, in agreement with the findings of Armenante and Nagamine [19]. Notably, Table 2 shows that lower liquid heights result in larger $N_{js}$ or $s$ values, which may be a characteristic of conical-based vessels. Ricard et al. [20] reported $N_{js}$ values for a 15º RCI in a dished-based vessel and a 45º RCI in a conical-based vessel, with $D/T = 0.6$ and $C/T = 0.07$ and a single beavertail baffle. Their $s$ values were calculated using $X$ as a mass fraction; recalculating using the more usual definition of $X$ as the solids mass ratio $\times 100$, then $s$ values of 3.5 and 3.8, respectively, were obtained. These compare rather well with the lowest clearance values in Table 2.

### 4. CONCLUSIONS

Measurements of the power number, dimensionless
Fig. 6. The effect of baffle arrangements on the 95% mixing time for the RCI in a conical-based vessel at $C/T = 0.16$. For comparison, data for a fully baffled flat-based vessel are also shown.

Fig. 7. The effect of baffle arrangements on the 95% mixing time for the RCI in a conical-based vessel at $C/T = 0.22$. 
Fig. 8. The effect of baffle arrangements on the 95% mixing time for the RCI in a conical-based vessel at $C/T = 0.31$.

Fig. 9. Dimensionless mixing times for various baffle arrangements at three impeller clearances.
Fig. 10. Just-suspended speeds at different impeller clearances (220 µm particles at 10% mass fraction): closed symbols $H/T = 0.75$; open symbols $H/T = 1.00$.

Fig. 11. Just-suspended speeds at different impeller clearances (540 µm particles with a single wall baffle): closed symbols $H/T = 0.75$; open symbols $H/T = 1.00$. 
mixing time and Zwietering’s values for solids suspension have been obtained from experiments using an RCI in a 0.29 m diameter tank, with a 90º conical-base. As with more conventional geometries, the power number is not much affected by the impeller clearance and there is only about a 10% reduction in $P_0$ caused by changing from a flat to a conical-base. The effects of partial baffling on the power draw are significant and power number correction factors have been presented. For a PBT the mixing times were significantly affected by the vessel base shape, but this effect was much reduced for the RCI. Mixing times calculated from Ruszkowski’s [16] correlation provided rather conservative estimates for the RCI in a conical based vessel. In general, a single wall baffle gave the shortest mixing times, whereas a single beavertail led to the longest $N_0\theta_95$ values. However, in all cases, the measured dimensionless mixing times, in the turbulent regime, were relatively short, indicating that macro-scale blending was unlikely to be a limiting factor in the operation of these vessels. Visual observations indicated that the flows generated in the apex of the cone were not conducive to particle suspension. Just-suspended impeller speeds generally increased with increasing impeller clearance and decreasing fill level. For solids suspension, a single wall or beavertail baffle was found to give lower Zwietering $s$ or $N_p$ values than the case with four wall baffles.

### Table 2. Fitted Zwietering $s$ values for the RCI configurations in conical-based vessels, showing the effect of liquid level, impeller clearance and baffle arrangement.

<table>
<thead>
<tr>
<th>Baffles</th>
<th>$C/T$</th>
<th>$H/T$</th>
<th>0.16</th>
<th>0.22</th>
<th>0.29</th>
<th>0.36</th>
<th>0.43</th>
<th>0.50</th>
<th>0.57</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 beavertail</td>
<td>0.75</td>
<td>4.3</td>
<td>4.9</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>1 wall</td>
<td>0.75</td>
<td>4.0</td>
<td>4.3</td>
<td>4.4</td>
<td>4.9</td>
<td>5.2</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>2 wall</td>
<td>0.75</td>
<td>4.7</td>
<td>5.6</td>
<td>6.0</td>
<td>4.8</td>
<td>5.1</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>3 wall</td>
<td>0.75</td>
<td>4.8</td>
<td>6.1</td>
<td>4.7</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>4 wall</td>
<td>0.75</td>
<td>5.5</td>
<td>6.7</td>
<td>—</td>
<td>—</td>
<td>6.2</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>1 beavertail</td>
<td>1</td>
<td>3.8</td>
<td>4.1</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>1 wall</td>
<td>1</td>
<td>3.3</td>
<td>3.9</td>
<td>4.5</td>
<td>4.6</td>
<td>4.8</td>
<td>5.0</td>
<td>5.2</td>
<td>5.3</td>
</tr>
<tr>
<td>2 wall</td>
<td>1</td>
<td>3.8</td>
<td>4.5</td>
<td>6.3</td>
<td>5.3</td>
<td>4.9</td>
<td>4.8</td>
<td>5.3</td>
<td>5.3</td>
</tr>
<tr>
<td>3 wall</td>
<td>1</td>
<td>4.4</td>
<td>4.5</td>
<td>—</td>
<td>—</td>
<td>5.8</td>
<td>6.0</td>
<td>6.6</td>
<td>6.6</td>
</tr>
<tr>
<td>4 wall</td>
<td>1</td>
<td>4.5</td>
<td>4.8</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

5. **REFERENCES**

Scale up study of retreat curve impellor stirred tank using LDA measurements and CFD simulations. 


Laboratory Evaluation of Imidacloprid against *Microtermes obesi* (Holmgren) (Isoptera: Macrotermitinae)

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Abstract: A laboratory bioassay was developed to test the toxicity, repellency and tunneling behavior of imidacloprid against *Microtermes obesi* (Holmgren). In this study, >90% of termites died after 96 h exposure to 100 µg mL⁻¹ of imidacloprid and after 168 h all the termites died at all the tested concentrations. When tested for persistence (exposure to soil aged one month after treatment), >90% mortality was observed in soil treated with 100 µg mL⁻¹, 50 µg mL⁻¹ and 25 µg mL⁻¹ after 120 h exposure. Repellency test results proved imidacloprid to be a non-repellent insecticide at all tested concentrations (i.e., 100 µg mL⁻¹, 50 µg mL⁻¹, 25 µg mL⁻¹, 12.5 µg mL⁻¹, 6.25 µg mL⁻¹, 3.125 µg mL⁻¹ and 1.562 µg mL⁻¹). When tested for F-1 (0.97) toxicity, it was also evident that it took more than 8 h to give 97% mortality. Tunneling behavior was also studied for cumulative tunnel distance, maximum tunnel height and number of tunnels. At higher concentrations, not only was there more mortality, but also less cumulative tunnel distance and a reduced number of tunnels.

Keywords: Toxicity, repellency, tunneling, imidacloprid, *Microtermes obesi*

1. INTRODUCTION

*Microtermes obesi* (Holmgren) is one of the most common termite species of Pakistan. It has been found attacking forest plants as well as timbers which are used as building material; doors and windows and ventilators are commonly destroyed. It builds underground nests in the soil. Despite many other measures available to control termites, including treated woods, baits, physical barriers, biological control agents, etc., the most effective and widely used method of control is the use of insecticides. Chemicals like silafluofen, imidacloprid, didecyl dimethyl ammonium chloride (DDAC), chlorpyrifos, fenvalerate, cypermethrin, permethrin, fenvalerate, spinosad, chlorfenapyr, thiamethoxam, bifenthrin, fluafenoxuron, fipronil and acetamiprid have been found effective for the control of different termite species [3–11, 14, 15, 17, 18, 20–23].

The present study aims to determine the efficacy of a slow acting insecticide, imidacloprid against *M. obesi* in fresh and one month post-treated laboratory soil.

2. MATERIALS AND METHODS

Workers of *M. obesi* used in this study were collected by traps placed in the lawns of the Lahore College for Women University, Lahore, Pakistan. The traps were brought to the laboratory, all the debris was removed and termites (workers and soldiers) were kept in plastic boxes with moist filter papers in constant darkness at 25-28°C and 80% r.h. for more than 14 days prior to assay in order to eliminate inactive termites and get active and healthy termite workers.

The soil (5–10 cm depth) used in this study was a sandy loam, free of contamination. It was
collected from Botanical Garden of the University. The soil was ground and passed through a 2 mm sieve, spread on a tray and oven-dried at 100°C for 24 h.

Imidacloprid (20 S.L.) was serially diluted to seven different concentrations, i.e., 100 µg mL⁻¹, 50 µg mL⁻¹, 25 µg mL⁻¹, 12.5 µg mL⁻¹, 6.25 µg mL⁻¹, 3.125 µg mL⁻¹ and 1.562 µg mL⁻¹. Contact toxicity testing of imidacloprid (20%) was done in a Petri dish (14 cm diameter). Each sample of 8.0 g soil was treated with 2 mL of a specific concentration of the termiticide with the help of a micropipette, then air dried for a few minutes. There were three replicates for each concentration. In the control sample, the soil was treated with distilled water only. Fourteen worker termites were released in each Petri dish and the dishes were sealed with parafilm. The dishes were kept in an incubator at 25-26°C and 80% r.h. The termites were examined at half hour intervals for 8 hours and subsequently after every 24 h. The number of dead termites was counted and tabulated at each examination. The contact toxicity bioassay of imidacloprid (20%) was terminated till 100% mortality was achieved. In order to determine the persistence of the insecticide, termite mortality was also checked in the one month old treated soil.

For the contact repellency test, the procedure was the same as for the contact toxicity test except that the soil was divided into two halves. One half of the soil was treated with 1.0 mL of the respective termiticide concentration and the other half with 1mL of the solvent. Repellency readings were taken after every 15 minutes for 2.5 h; the number of termites were counted on the treated and untreated sides and tabulated. The contact repellency test was conducted for freshly treated soil and for the one month post-treated soil. A treatment concentration was considered as repellent when 30 or more of the termites (sum of three replicates) were observed on the untreated soil [17].

Tunneling bioassays were performed by the procedure suggested by Grace [10]. The apparatus (Fig. 1) consisted of the following three compartments:

Component 1: A plastic vial containing untreated soil and filter paper of size of vial. An untreated filter paper weighing about 0.07 grams was placed in one of the two vials, which also contained the moistened soil.

Component 2: A plastic “sandwich” or tunneling arena, containing treated soil.

Component 3: A second vial containing untreated sand and an additional food source like moist filter paper the size of the vial.

The vials were connected serially by 1.5 cm long Tygon tube. Each of these vials contained 10.0 g untreated soil, 2.0 mL distilled water and filter paper as food. The treated soil was poured into the tunneling arena, and 2.0 mL distilled water added by pipette along the open top edge. This water moistened the soil of the arena. The top edge of the each tunneling arena was sealed with transparent plastic tape in order to reduce evaporation. One hundred termites were released in the one of the two vials. The vials were capped and the caps were pierced with air holes by using a heated insect pin. Each concentration of insecticide and the control were replicated thrice. All experimental units were kept in an incubator at 26°C. Test setups were examined at 24 h intervals for 7 days. At each examination, the number of tunnels, the length of the tunnels, and the number of surviving and affected individual termites were measured and counted.

The data were analyzed statistically. Means were separated by Tukeys Honestly Significant Difference (HSD) test using GraphPad Prism Version 4.00 for Windows, GraphPad Software, San Diego California USA, (www.graphpad.com).

3. RESULTS AND DISCUSSION

The mean percent mortality of M. obesi (Holmgren) treated with different concentrations of imidacloprid: 100% mortality was observed at 100 µg mL⁻¹, after 6 days of exposure to insecticide (Table 1). After
8 days of treatment, 100% mortality was observed at all the tested concentrations. The mortality was 0% with the control treatment. For testing the persistence of imidacloprid, one month old treated soil stored in the dark at 26°C was also tested for toxicity. The mortality was 100% with 100 µg mL⁻¹ after 7th day of the testing period, and all the termites exposed to other experimental dosages were observed dead after 9th day of the test period. There were significant differences between all treatments (P<0.001). For example, there existed a significant relationship between the testing time and mortality of Microtermes obesi (Holmgren) in soil treated with different concentrations of imidacloprid after 8 days exposure.

### Table 1. Mortality (mean ± SD) of Microtermes obesi (Holmgren) in soil treated with different concentrations of imidacloprid after 8 days exposure.

<table>
<thead>
<tr>
<th>Hours</th>
<th>100 µg mL⁻¹</th>
<th>50 µg mL⁻¹</th>
<th>25 µg mL⁻¹</th>
<th>12.5 µg mL⁻¹</th>
<th>6.25 µg mL⁻¹</th>
<th>3.125 µg mL⁻¹</th>
<th>1.562 µg mL⁻¹</th>
<th>Control</th>
<th>P(1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 (day 1)</td>
<td>A*</td>
<td>a</td>
<td>a</td>
<td>a</td>
<td>a</td>
<td>a</td>
<td>a</td>
<td>a</td>
<td>a</td>
</tr>
<tr>
<td>24 (day 2)</td>
<td>b</td>
<td>b</td>
<td>b</td>
<td>B</td>
<td>b</td>
<td>b</td>
<td>a</td>
<td>P&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>48 (day 3)</td>
<td>c</td>
<td>c</td>
<td>c</td>
<td>C</td>
<td>c</td>
<td>c</td>
<td>a</td>
<td>P&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>72 (day 4)</td>
<td>c</td>
<td>c</td>
<td>C</td>
<td>d</td>
<td>d</td>
<td>d</td>
<td>a</td>
<td>P&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>96 (day 5)</td>
<td>d</td>
<td>d</td>
<td>d</td>
<td>D</td>
<td>e</td>
<td>e</td>
<td>e</td>
<td>a</td>
<td>P&lt;0.0001</td>
</tr>
<tr>
<td>120 (day 6)</td>
<td>d</td>
<td>d</td>
<td>e</td>
<td>F</td>
<td>f</td>
<td>f</td>
<td>e</td>
<td>a</td>
<td>P&lt;0.0001</td>
</tr>
<tr>
<td>144 (day 7)</td>
<td>d</td>
<td>d</td>
<td>e</td>
<td>F</td>
<td>f</td>
<td>f</td>
<td>f</td>
<td>a</td>
<td>P&lt;0.0001</td>
</tr>
<tr>
<td>168 (day 8)</td>
<td>d</td>
<td>d</td>
<td>e</td>
<td>f</td>
<td>f</td>
<td>f</td>
<td>g</td>
<td>a</td>
<td>P&lt;0.0001</td>
</tr>
</tbody>
</table>

* Means followed by similar letters within the column indicate non-significant differences (Tukey’s HSD test).

### Table 2. Mortality (mean ± SD) of Microtermes obesi (Holmgren) in soil treated with different concentrations of imidacloprid (1 month old treatment).

<table>
<thead>
<tr>
<th>Hours</th>
<th>100 µg mL⁻¹</th>
<th>50 µg mL⁻¹</th>
<th>25 µg mL⁻¹</th>
<th>12.5 µg mL⁻¹</th>
<th>6.25 µg mL⁻¹</th>
<th>3.125 µg mL⁻¹</th>
<th>1.562 µg mL⁻¹</th>
<th>Control</th>
<th>P(1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 (day 1)</td>
<td>A*</td>
<td>a</td>
<td>a</td>
<td>A</td>
<td>a</td>
<td>A</td>
<td>a</td>
<td>a</td>
<td>P&lt;0.0001</td>
</tr>
<tr>
<td>24 (day 2)</td>
<td>b</td>
<td>b</td>
<td>a</td>
<td>A</td>
<td>b</td>
<td>B</td>
<td>b</td>
<td>a</td>
<td>P&lt;0.0001</td>
</tr>
<tr>
<td>48 (day 3)</td>
<td>c</td>
<td>c</td>
<td>b</td>
<td>B</td>
<td>c</td>
<td>C</td>
<td>c</td>
<td>a</td>
<td>P&lt;0.0001</td>
</tr>
<tr>
<td>72 (day 4)</td>
<td>d</td>
<td>d</td>
<td>c</td>
<td>C</td>
<td>d</td>
<td>D</td>
<td>d</td>
<td>a</td>
<td>P&lt;0.0001</td>
</tr>
<tr>
<td>96 (day 5)</td>
<td>e</td>
<td>e</td>
<td>d</td>
<td>D</td>
<td>e</td>
<td>E</td>
<td>e</td>
<td>a</td>
<td>P&lt;0.0001</td>
</tr>
<tr>
<td>120 (day 6)</td>
<td>f</td>
<td>f</td>
<td>e</td>
<td>E</td>
<td>f</td>
<td>f</td>
<td>f</td>
<td>a</td>
<td>P&lt;0.0001</td>
</tr>
<tr>
<td>144 (day 7)</td>
<td>g</td>
<td>g</td>
<td>e</td>
<td>F</td>
<td>g</td>
<td>G</td>
<td>g</td>
<td>a</td>
<td>P&lt;0.0001</td>
</tr>
<tr>
<td>168 (day 8)</td>
<td>g</td>
<td>g</td>
<td>f</td>
<td>F</td>
<td>h</td>
<td>Gh</td>
<td>gh</td>
<td>a</td>
<td>P&lt;0.0001</td>
</tr>
<tr>
<td>192 (day 9)</td>
<td>g</td>
<td>g</td>
<td>f</td>
<td>F</td>
<td>h</td>
<td>Gh</td>
<td>gh</td>
<td>a</td>
<td>P&lt;0.0001</td>
</tr>
</tbody>
</table>

* Means followed by similar letters within the column indicate non-significant differences (Tukey’s HSD test).
and the dose applied. So the results showed, not unexpectedly, that the highest termite mortality was observed at 100 µg mL⁻¹ and 50 µg mL⁻¹ and lowest mortality was observed at 1.562 µg mL⁻¹. As discussed in Materials and Methods, it is evident that imidacloprid was non-repellent at all the tested concentrations against the termites even after one month exposure.

Laboratory experiments were also conducted to test the tunneling behavior of *M. obesi* (Holmgren) against imidacloprid at all the seven tested concentrations of insecticides. The objective of this study was to evaluate cumulative tunnel distance, maximum tunnel height and number of tunnels after the first and seventh days of the treatment.

The maximum tunnel height after the first day of treatment, for the soil treated with different concentrations of imidacloprid, was 61.53, 60.27, 58.83, 55.60, 47.47, 44.57, 36.80 and 33.63 mm for the control, and 1.562, 3.125, 6.25, 12.5, 25, 50 and 100 µg mL⁻¹ treatments, respectively. Different insecticide concentrations highly significantly affected maximum tunnel height after day-one (P<0.0001). The mean tunnel height recorded after one day was 10.0, 9.0, 7.0, 6.0, 4.3, 3.3 and 2.3 mm for 1.562, 3.125, 6.25, 12.5, 25, 50 and 100 µg mL⁻¹, respectively. For control treatment the mean number of tunnels was 11.0. The ANOVA test revealed that different concentrations of the insecticide significantly affected the number of tunnels after day 1 (P<0.0001; Table 3).

After 7th day of treatment application, the cumulative tunnel distance was 282.5 mm in control and 374.6, 369.3, 338.7, 302.3, 257.6, 239.4 and 208.3 mm in soil treated with 1.562, 3.125, 6.25, 12.5, 25, 50 and 100 µg mL⁻¹, respectively. Highly significant differences were observed in tunnel distance with different concentrations of imidacloprid (P<0.0001). Mean maximum tunnel distance after 7th day of soil treatment application with different concentrations of imidacloprid was 80.3, 76.7, 75.5, 70.8, 65.5, 61.6 mm with 53.6 for 1.562, 3.125, 6.25, 12.5, 25, 50 and 100 µg mL⁻¹, respectively. In control treatment, maximum tunnel length after 7th day was 82.6 mm. Different insecticide concentrations affected maximum tunnel distance highly significantly (P<0.0001; Table 3).

Mean number of tunnels after 7th day was 17.0, 15.7, 15.0, 13.0, 12.0, 8.0 and 5.0 with insecticide concentrations of 1.562, 3.125, 6.25, 12.5, 25, 50 and 100 µg mL⁻¹, respectively. With control treatment, the number of tunnels was 17.7. Analysis of variance revealed significant differences for this parameter at different concentrations of imidacloprid (P<0.0001; Table 3).

Fipronil acts at the same target site as the organochlorine cyclodienes, with similar effects on insects [2]. Fipronil has been shown to have much greater affinity for insect GABA receptors as

**Table 3.** Tunneling behaviour of *Microtermes obesi* (Holmgren) (mean ± SE) on 7th day after treatment with imidacloprid.

<table>
<thead>
<tr>
<th>Concentration (µg mL⁻¹)</th>
<th>Cumulative tunnel distance (mm)</th>
<th>Maximum tunnel height (mm)</th>
<th>No. of tunnels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>482.5±0.491</td>
<td>92.6±0.491</td>
<td>27.7±0.333</td>
</tr>
<tr>
<td>1.562</td>
<td>374.6±0.406</td>
<td>80.3±0.208</td>
<td>17.0±0.577</td>
</tr>
<tr>
<td>3.125</td>
<td>369.3±0.569</td>
<td>76.7±0.491</td>
<td>15.7±0.333</td>
</tr>
<tr>
<td>6.25</td>
<td>338.7±0.463</td>
<td>75.5±0.433</td>
<td>15.0±0.577</td>
</tr>
<tr>
<td>12.50</td>
<td>302.3±0.754</td>
<td>70.8±0.467</td>
<td>13.0±0.577</td>
</tr>
<tr>
<td>25</td>
<td>257.6±0.463</td>
<td>65.5±0.406</td>
<td>12.0±0.577</td>
</tr>
<tr>
<td>50</td>
<td>239.4±0.404</td>
<td>61.6±0.436</td>
<td>8.0±0.577</td>
</tr>
<tr>
<td>100</td>
<td>208.3±0.462</td>
<td>53.6±0.462</td>
<td>5.0±0.577</td>
</tr>
</tbody>
</table>
For many years, researchers have been testing both repellent and non-repellent termiticides, but due to environmental safety considerations, non-repellent termiticides are now more frequently used because they have a delayed mode of action [13, 25]. Various studies have been carried out to test the efficacy of different insecticides on different termite species in different parts of the world. Su et al [26] reported that neither species Coptotermes heimi nor M. obesi would penetrate permethrin treated soil. Remmen and Su [25] also proved the efficacy of fipronil and found that 2 µg mL\(^{-1}\) of fipronil that can fully stop the penetration of Coptotermes formosanus Shiraki and Reticulitermes flavipes Kollar in a treated barrier layer.

In Pakistan, various researchers have also tested the efficacy of different commercially available insecticides on different termite species. Akhtar and Shazia [1] reported that nimbokil and disodium tetraborate decahydrate were not toxic to M. championi even at higher doses. Imidacloprid was not tested for any termite species in Pakistan prior to the present study. Sheikh et al [24] evaluated the toxicity of Tenekil® (polychlorinated petroleum hydrocarbon), Termidor® (fipronil) and Terminus® (chlorpyrifos) against Heterotermes indicola (Wasmann) in soil. Similarly, Manzoor et al [16] studied the repellence, toxicity and tunneling ability of Coptotermes heimi in response to bifenthrin (Biflex®), phenylpyrazole, fipronil (Termidor) and polychlorinated petroleum hydrocarbon (Tenekil), the results of the study were that Biflex is repellent, while Termidor and Tenekil did not show repellent effect at any concentration. Our data cannot be directly extrapolated to field situations, so investigations for performance in the field must still be carried out. Toxicity, repellency and tunneling response were tested in this study only in the sandy loamy soil, and previous studies revealed that soil type also influences the bioavailability of imidacloprid. Ramakrishnan et al [19] studied feeding inhibition and mortality in various soils and concluded that there was significant interaction between imidacloprid and the soils. So different soil types should be a part of any future efficacy testing.

4. REFERENCES


Studies on Three Species of *Dictyota* (Phaeophycota) from Karachi Coast of Pakistan

Alia Abbas1* and Mustafa Shameel2

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Abstract: Three species of *Dictyota* i.e. *D. ceylanica* Kützing, *D. ciliolata* Kützing and *D. linearis* (C. Agardh) Greville were collected from the coastal areas of Karachi (Pakistan) during March 2007 and October 2009. They were investigated in detail for their morphology, anatomy and reproduction. Anatomically their thalli were studied in detail for the first time which revealed some interesting features.

Keywords: Marine algae, Phaeophycota, *Dictyota*, Anatomy, morphology, reproduction

1. INTRODUCTION

Like other areas of Arabian Sea, the coastline of Pakistan is also rich in the species diversity of brown algal genus *Dictyota* J. V. Lamouroux, *nom. cons.* [1, 2]. Several species were reported to grow in the seashore waters of Karachi [3, 4], but no detailed study has been made in this connection. During 2006-2009 a large collection survey of brown seaweeds was made from various coastal areas of Karachi, where three species were collected. They were investigated in detail for their morphology, anatomy and reproduction as presented here.

2. MATERIALS AND METHODS

The specimens were collected from Buleji, the coastal area of Karachi (Pakistan) during March 2007 and October 2009, and preserved in 4 % formaldehyde-seawater solution. The herbarium sheets of the materials were prepared and deposited in the Herbarium (FUU-SWH), Department of Botany, Federal Urdu University of Arts, Science & Technology, Karachi, Pakistan. In order to study internal structures, cross sections (C.S.) of the fresh material were obtained by freehand cutting with shaving blades, which were stained, mounted, slides were prepared and examined under microscope, photographs were taken and developed, and photographic plates were prepared as described recently [5].

3. RESULTS

The collected specimens on general observation and microscopic examination revealed the presence of three species of *Dictyota*, which may be distinguished as follows:

1. Dark coloured lines on thallus surface ........................................... 2
   No such lines on thallus surface ...*D. ceylanica*

2. Thallus profusely branched ...........*D. ciliolata*
   Thallus dichotomously branched..*D. linearis*

These species differ from one another in several body characters, as shown in the Table I. Their general characters and anatomical features are given below.

1. *Dictyota ceylanica* Kützing 1859: 11

References

Morphological characters

Thalli reddish brown, erect, flat, dichotomously branched, surface smooth, margins undulate with prominent ridges; apex emarginated with a triangular notch, apex of lobes obtuse; base trenched by means of a compact holdfast; thallus 8–10 cm long, 2–5 mm broad at the apex, 0.8–1.2 cm broad at middle and 1.0 - 1.8 cm broad at the base; dichotomy 0.5–1.5 cm apart, angle between dichotomy rounded at lower portion (Fig. 1).

Anatomical features

In surface view: thallus surface dark brown, peripheral cells cubical and rectangular, arranged horizontally; sori scattered on both surfaces of the thalli, dark brown, rounded or oval or cubical in shape (Fig. 2).

In the apical portion: thallus consists of peripheral layers enclosing a single layered medulla; peripheral cells small, cubical, thin walled, with dense phaeoplasts, 20–25 µm in length and 17.5–25.0 µm in breadth; medullary cells large, quadratic or thick walled, poor in contents, 100–125 µm in length and 100.0–112.5 µm in breadth (Fig. 3)

In the middle part: peripheral cells small, cubical, thin walled, with dense phaeoplasts, 25.0–37.5 µm in length and 12.5–25.0 µm in breadth; medullary cells large, thick walled, poor in contents, cubical, 112.5–125.0 µm in length and 110.0–122.5 µm in breadth (Fig. 4).

In the basal portion: peripheral cells small, thin walled, cubical, with dense phaeoplasts, 20–25 µm in length and 25–30 µm in breadth; medullary cells large, thick walled, cubical, poor in contents, 87.5–125.0 µm in length and 87.5–100.0 µm in breadth; marginal medullary cell long, thin-walled, poor in contents, rectangular, 25 - 100 µm in length and 20–50 µm in breadth (Fig. 5).

Reproductive structures

Thalli dioecious; antheridia present in sori, club-shaped, dark brown in colour, cylindrical, upper portion swollen, 5–10 antheridia present in a sorus, sori scattered on both surfaces of the thallus; antheridia 87.5–125.0 µm in length and 25–37.5 µm in breadth (Fig. 6).

Type locality

Sri Lanka.

Habitat

Benthic on mid-littoral rocks and edges of pools at Goth Haji Ali, Buleji (Leg. Alia Abbas 18-10-2008).

Local distribution

Karachi: Buleji.

Distribution in the Indian Ocean

India, Kenya, Pakistan, Seychelles, South Africa, Sri Lanka, Tanzania and Yemen.

Remarks

This species is of rare occurrence at the coast of Karachi. Although it was collected earlier as drift material from Buleji coast but was not taxonomically described [3]. The present study is the first taxonomic and anatomical investigation of this species from the coast of Pakistan. Its identification was confirmed by Prof. Dr. Olivier De Clerck (pers. comm.).

2. Dictyota ciliolata Kützing 1859: 12

Synonym

Dictyota ciliata J. Agardh 1841: 5, nom. illeg.

References


Morphological characters

Thalli dark brown in colour, orbicular in shape, profusely branched, branches arise from all sides of the thallus; margins entire, base acuminate and dichotomously branched; apex of branches emarginated, apex of lobes obtuse and broad below the tip, surface smooth; attached with the help of a cuneate compact disk, 4 mm long and 3 mm broad;
Fig. 1-4. *Dictyota ceylanica*: 1. Habit of the thallus; 2. Surface view of thallus; 3. C.S. of apical portion; 4. C.S. of middle part of thallus.
Fig. 5-6. *Dictyota ceylanica*: 5. C.S. of basal portion containing antheridial sori on both surfaces; 6. Antheridia in enlarged view.

Fig. 7-8. *Dictyota ciliolata*: 7. Habit of the thallus, 8. Surface view of thallus.
thallus 5–6 cm high, 2–4 mm broad at the apex, 3–4 mm broad at the middle, and 1–2 mm at the base; small proliferations arise from basal and upper parts of the thallus; dark brown lines present on the thallus surface (Fig. 7).

**Anatomical features**

In surface view: rectangular blocks forming horizontal and vertical lines; peripheral cells arranged in longitudinal rows, small, rectangular, 15–30 µm in length and 10.0–22.5 µm in breadth (Fig. 8). Thallus in its entire length consists of upper and lower peripheral layers and a central single layered medulla.

In the apical portion: peripheral layers consist of small, cubical or squarish, thin walled cells, with dense chromatophores, cell-wall thickness 2.5 µm, 22.5–25.0 µm in length and 15.0–20.0 µm in breadth; single layered medulla consists of large, squarish, thick walled cells, poor in contents, cell-wall thickness 5.0–7.5 µm, 62.5–87.5 µm in length and 75.0–87.5 µm in breadth (Fig. 9).

In the middle part: peripheral cells small, cubical, thin walled, with dense phaeoplasts, 7.5–17.5 µm in breadth, cell-wall thickness 2.5 µm, some large cells are present where cell-wall of medulla is formed, large in size, 25 µm in length and 25 µm in breadth; medullary cells large, cubical, thick walled, poor in contents, cell-wall thickness 7.5–10.0 µm, 75–100 µm in length and 75.0–87.5 µm in breadth; marginal medullary cell small, semi-circular, 15.0–27.5 µm in length and 22.5–30.0 µm in breadth.

In the basal portion: peripheral cells small, cubical or squarish, thin walled, with dense phaeoplasts, cell-wall thickness 2.5 µm, 10.0–22.5 µm in length and 10–25 µm in breadth; medullary cells large, cubical, thick walled, poor in content, cell-wall thickness 7.5 µm, 50.0–87.5 µm in length and 50.0–87.5 µm in breadth. Cells of dorsal peripheral layer large, cubical, slightly elongated, loosely arranged, light brown, cells in the ventral layer small, flattened or cubical, dark brown in colour (Fig. 10). On both sides of thallus, peripheral layers covered with a layer of epiphytes or deposition of calcareous material. Marginal medullary cell cubical or slightly rounded, small, thick-walled, 20.0–37.5 µm in length and 20.0–32.5 µm in breadth (Fig. 11).

**Reproductive structures**

Reproductive bodies were not observed, collected thalli were only in the vegetative stage.

**Type locality**

La Guaira, Venezuela

**Habitat**

Benthic on mid-littoral rocks and edges of rocky pools at Goth Haji Ali, Buleji (Leg. Alia Abbas 18-10-2008).

**Local distribution**

Karachi: Manora, Buleji, Cape Monze and Goth Manjar.

**Distribution in the Indian Ocean**

Australia, India, Kenya Kuwait, Madagascar, Pakistan, Réunion, Singapore, Sri Lanka, Tanzania and Yemen.

**Remarks**

The conspecificity of *Dictyota ciliolata* Kützing and *D. ciliata* J. Agardh was proposed by J. Agardh and he erroneously retained the latter name on the basis of the date of priority. But this name is nom. illeg., because it is a later homonym of *D. ciliata* Lamouroux 1809: 41 [10], therefore the correct name for the present species would be *D. ciliolata*. Its identification was confirmed by Prof. Dr. Olivier De Clerck (pers. comm.).

3. ** Dictyota linearis** (C. Agardh) Greville 1830: 13

**Basionym**

*Zonaria linearis* C. Agardh 1817: 20

**Synonyms**


**References**


**Morphological characters**

Thalli olive green in colour; up to 15 cm long, 5-10 mm broad at the base, 3-8 mm broad at the middle and 2–4 mm broad at the apex; surface smooth,
Fig. 9-11. *Dictyota ciliolata*: 9. C.S. of apical portion; 10. C.S. of basal part showing different peripheral layers; 11. Marginal medullary cell in the basal portion with deposition on the thallus.

Fig. 12. *D. linearis*: Habit of the thallus.
margins entire or slightly undulate, a number of proliferations arise from the margins and from the apex; dichotomously branched, dichotomy 0.4-2.0 cm apart; dark coloured vertical lines present on the surface of the thallus; thalli broader at the base and narrow at the apex; attached with the help of a small, solid holdfast (Fig. 12).

**Anatomical features**

In surface view: peripheral cells dark coloured, variable in size and shapes, cubical, rectangular, polygonal and hexagonal, with dense phaeoplasts, 17.5–37.5 µm in length and 12.5–37.5 µm in breadth (Fig. 13); dark blackish brown spots present in such a way that dark coloured vertical lines appear on the surface of the thallus.

In the apical portion: thallus width 125 µm, composed of 3 layers i.e. upper and lower peripheral layers and a single medullary layer; peripheral cells small, thin walled, dark brown, with dense phaeoplasts, flask shaped, upper portion narrow and lower portion broad, intercellular spaces present, 12.5-25.0 µm in length and 12.5–20.0 µm in breadth (Fig. 14); medullary cells thick-walled, cell-wall thickness 2.5 µm, cubical, poor in contents or a single, large, dense phaeoplast present, 45.0–72.5 µm in length and 32.5–75.0 µm in breadth (Fig. 15). In the margin single, small, thick walled medullary cell, poor in contents, cubical or slightly rounded, 47.5–65.0 µm in length and 50-60 µm in breadth.

In the middle part: thalli consists of 3 layers i.e. upper and lower peripheral layers and a single medullary layer; peripheral cells small, thin walled, flask shaped, upper portion narrow and lower portion broad, dark coloured with dense phaeoplasts, 15.0-27.5 µm in length and 7.5–12.5 µm in breadth; medullary cells large, thick walled, poor in contents, cubical or squarish, variable in size, 50.0–75.0 µm in length and 77.0–82.5 µm in breadth (Fig. 16). In the margin medullary cell small, slightly rounded, intercellular spaces absent, thick walled, poor in contents, 40.5–57.5 µm in length and 42.5–55.0 µm in breadth.

In the basal portion: thalli composed of 3 layers, i.e., upper and lower peripheral layers and a single medullary layer; peripheral cells small, thin walled, dark brown, cubical or squarish, some cells slightly rounded, intercellular spaces present, 7.5–12.5 µm in length and 5.0–10.0 µm in breadth (Fig. 17); medullary cells large, thick walled, poor in contents, cubical, or slightly rounded, 25.0-42.5 in length and 22.5–45.0 µm in breadth. In the margin medullary cell small, thick walled, poor in contents, cubical or rounded, 75.0-105.0 µm in length and 50.0–75.0 µm in breadth (Fig. 18).

**Reproductive structures**

Oval or rounded dark brown, stalked, sporangia arise from peripheral cells, present on both surfaces (Fig. 19), found singly, 45.5–75.5 µm in length and 50.0–62.5 µm in breadth (Fig. 20).

**Syntype localities**

Cádiz, Spain; “ad oras Americae”.

**Habitat**

Collected as drift material and benthic on mid–littoral rocks and edges of the rocky pools at Goth Haji Ali, Buleji (Leg. Alia Abbas 17-3-2007, 14-3-, 24-10- & 29-11-2008, 26-1-, 7-3-, 31-3- & 16-10-2009).

**Local distribution**

Karachi: Manora and Buleji.

**Distribution in the Indian Ocean**

Malaysia, Pakistan, South Africa and Tanzania.

**Remarks**

Sonder [18] has reported a variety from Australia, which he named as *D. linearis* var. *minor* Sonder. It is a nom. inval. because he did not provide any description or illustration for this taxon [10]. Similarly, Salim [19] also reported *D. littoralis* Anand from Karachi coast of Pakistan. It is also nom. inval., as no description of this species is available anywhere. Therefore, De Clerck [12] considered the occurrence of this species in the Indian Ocean as doubtful. The species *D. linearis* has so far been reported from the coast of Pakistan only in the Arabian Sea and apart from the report of Begum & Khatoon [3] has not been described by any other researcher. This is the first taxonomic investigation and a detailed anatomical study of this species from Pakistan.
Fig. 17-20. Dictyota linearis: 17. Peripheral cells in the basal part; 18. C.S. of basal portion with marginal cells; 19. C.S. of thallus with sporangia on both surfaces; 20. Sporangium arising from a peripheral cell.
3. DISCUSSION

*Dictyota* is a commonly occurring genus of the family Dictyotaceae (order Dictyotales, class Dictyophyceae, phylum Phaeophyta; *fide* [20]) at the coast of Pakistan. It is a key component of many coastal ecosystems of tropical to warm temperate areas [21]. It is characterized by parenchymatous, flattened thalli which grow by a single transversely oriented apical cell, and is distinguished from its allied genera such as *Dilophus, Glossophora, Glossophorella,* and *Pachydictyon* by the structure of peripheral and medullary layers, as well as the relative abundance of surface proliferations. Several species of *Dictyota* were observed to grow at the coast of Karachi [1, 3, 4]. Additionally, three more species were collected and investigated here, which are distinguished from one another in several thallus characters (Table 1).

Taxonomy of *Dictyota* has a long and troubled history. The inability to distinguish morphological plasticity from fixed diagnostic traits which separate its different species has severely confounded species delineation [22, 23]. The traditional distinction of various species has repeatedly been criticized by phycologists, the absence of sound molecular data has so far discouraged any new taxonomic proposal. Phylogenetic analysis of *rbcL* gene, partial 26S rDNA sequence and combined data sets were carried out on several European species of *Dictyota* [21, 23]. Similar studies on the specimens from Pakistan might reveal their exact taxonomic position.

5. ACKNOWLEDGEMENTS

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6. REFERENCES


Taxonomic Studies of Freshwater Algae from Taxila, Pakistan

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Abstract: A taxonomic study of algal flora on the basis of their morphological and cytological features was conducted for identification up to species level. In the present study we collected a total number of 25 species of fresh water algae, 2 species belonged to class Ulvophyceae, 2 Zygnemophyceae, 7 Chlorophyceae and remaining 14 belonged to class Cyanophyceae from the different freshwater habitats of Taxila zone. It is a first comprehensive taxonomical study from Taxila and its surrounding areas.

Keywords: Algae, freshwater, Chlorophyceae, zygnemophyceae, cyanophyceae

1. INTRODUCTION

Algae are unicellular or multicellular, photosynthetic but lake true leaves, stems and roots. Their habitat is fresh water and moist areas. Algae have a great value to life on earth. As they are primary producers and play an important role in food chains mostly in aquatic environment & ecosystem [1]. Algae also use in the water cleaning and determination of pollution [2]. Taxila is an important archaeological place in the Rawalpindi District of the Punjab province in Pakistan. It is located about 33 km northwest of Islamabad and Rawalpindi and lies about 550 meters above the sea level. The weather of Taxila is moist subtropical with average rainfall of 990 mm. Most of the rainfall in study areas occurs in monsoon season. The algal samples were collected from Taxila and its surroundings for identification and classification on the basis of their taxonomical characteristics and properties.

2. MATERIALS AND METHODS

Twenty five samples of freshwater algae were collected from different freshwater habitats of Taxila, Pakistan and its surrounding areas during winter, spring and summer seasons from the streams, slow running water, ponds and sides of stagnant ponds. The samples were washed carefully to remove dust particles and then were preserved in 3 % formalin solution in small glass bottles, numbered and labeled according to their habitat. Then these samples were brought in the laboratory of Botany Department, Government College University, Faisalabad. Algal samples were placed on glass slides, teased into pieces, using fine needles, and then covered with cover slips. The slides were placed under the electron-microscope. We determined the taxonomy of samples to the level of species by comparison with published information on taxonomy of taxonomic identification of algae [3–8].

3. RESULTS

A taxonomic study of algal species was conducted on the basis of their morphological and cytological features for identification identified up to species level. On the basis of their morphological and cytological features the following 25 species of fresh water algae in which 9 species belong to genus Oscillatoria, 4 species belonged to
genus *Stigeoclonium*, 3 species belonged to genus *Microspora*, 3 species belonged to genus *Phormidium*, 2 species belonged to genus *Closterium*, 2 species belonged to genus *Rhizoclonium*, 1 species belonged to genus *Chroococcus* and 1 species of genus *Nostoc* was identified and their classification arranged according to recently proposed pattern. Their taxonomical characters are given below:

1: *Chroococcus dispersus* (Keissler) Lemmermann 1904: 102

**General characters:**
There colonies were small with a mucous cover of 3 to 15 cells. The cells were spherical; pale blue green, 4.1 to 4.7 μm in diameter.

2: *Closterium praelongum* Brébisson 1856: 152

**General characters:**
The filaments of this species are colorless and lightly striated almost 10 to 14 striate in 10.5 μm. The both ends are suddenly tapered, apex is 2-3 μm wide and there are 5 pyrenoids, 2-8 granules on terminal. The cell walls are smooth & colorless; the filaments are 251 μm long and 13.5 μm in diameter.

3: *Closterium strigosum* Brébisson 1856: 153

**General characters:**
The cell wall of the filaments of this species also smooth, colorless and apexes are fairly incurved & 4-5.5 μm broad. There are 2 to 4 pyrenoids, the cells are freely move within the filaments and the length of filament is 168 μm & 8-10 μm in diameter.

4: *Microsporafloccosa* (Vaucher) Thuret 1850: 222

**General characters:**
The cells are cylindrical in shape and rarely contracted at cross walls. The filaments were unbranched, the length is 22 to 23 μm & diameter is 13 to 14 μm. The color of it is light blue and the filaments are disassociating into H-pieces on fragmentation. The cell wall divided into two sections and show overlapping in the center regions where segment of deadly cell protrudes as indicated by broken ends of filament.

5: *Microsporatennerrima* (Kützing) Gay 1886: lvi

**General characters:**
The cells are cylindrical but short and thallus have unbranched filaments. It dissociate into H-pieces on fragmentation, filaments are 12-14 μm long and 6-8 μm wide. The structures of chloroplast varies, it may be folded, in an asymmetrical plates or a network of strands and parietal in appearance. The cell wall divided into two sections and show overlapping in the center regions where segment of deadly cell protrudes as indicated by broken ends of filament.

6: *Microsporawittrockii* (Wille) Lagerheim 1887

**General characters:**
This alga has unbranched filaments, the length of filaments is 33-36 μm and 22-25 μm in diameter. The cells are cylindrical, long and not contracted at cross walls. The color of filaments is yellowish green. The chloroplast appears in the shape of a thin sheet with perforations. The cell wall is smooth and colorless.

7: *Nostocsphaericum* Vaucher ex Bornet & Flahault 1888: 208

**General characters:**
The clonies of *Nostocsphaericum* are spherical in shape and yellowish brown in color. The cell walls are rough due to trichomes which are freely entangled. There is no individual sheath of each cell, the cells are 6 μm wide and some heterocyst appears which are spherical in shape.

8: *Oscillatoria acuminata* Gomont 1892: 227

**General characters:**
The thallus of *oscillatoria acuminata* is reddish brown in color, adhesive, gristly, smooth and 2 cm in diameter. The filaments are 5-6 μm in length, rarely contracted at joints and disperse the granules all over the filament. Thallus has straight, weak & unbranched trichomes, the diameter of it is 3-6 μm. The apices are lightly tapering and many apices have extremely long, thin, spike like points which are 2 μm broad & 31μm long, instantly and curved. The cross wall is visible, apical cells are sharply pointed. Sheaths are slim, fragile, colorless and internally dissolved into amorphous mucus, so
complicated to see. Heterocysts are absent.

9: Oscillatoria agardhii var. Isothrix Skuja 1948: 49

General characters:
The apical cells are appears in this species which are shorten and pointed in shape, with or without a calyptras. It also have pseudo vacuoles and the length of the filaments is 3-5 µm & 5-7 µm in diameter. The trichomes appear around their entire length which are straight, capitate and some are granular. Trichomes are briefly tapering at the anterior end and do not contracted at the cross wall. Trichomes are interwoven to form a blue green plant mass.

10: Oscillatoria amoena (Kützing) Gomont 1892: 225

General characters:
The color of its thallus is blue green; the filaments are 2.0-4.8 µm in length and 3-13 µm in diameter. Trichomes cover the filaments which are straight, briefly curved and it contracted at the plane septa. The end of filaments is steadily attenuated; cells have dull blue green color, the end cell capitate with calyptra and generally conical.

11: Oscillatoria amphibia C. Agardh 1827: 632

General characters:
The thallus of this species is deep bluish green, trichomes are instantly and some are twisted. The cross walls are not contracted, cells are pale blue green, the diameter of cells is 2-3 µm but it three time much longer then broad, its length is 4-8 µm. There is tow granules at the septa, apices are not thinned, not globose, end cells are rounded but not capitates and calyptras is not present.

12: Oscillatoria anguina Bory ex Gomont 1892: 214

General characters:
The thallus of oscillatoriaanguina is dark green in color, trichomes are thinned, straight and having a u-shaped calyptras at the end. The cell walls occasionally granulated 6-9µ wide and uncontracted at cross wall. The length of cells is 2.8-4 µm and diameter is 5.8-8 µm. The end cells are globose and covered by a slightly thickened membrane, cell contents are grainy.

13: Oscillatoria angusta Koppe 1924: 641

General characters:
The thallus of this species is yellowish green but its trichomes are colorless and straight. The width of cells is 1.2-1.8 µm and length is 3.6-4.5 µm. The cell wall is granulated and not contracted at cross walls. The end cells are rounded and gas vacuoles are not present.

14: Oscillatoria calcuttaensis Biswas 1925: 5

General characters:
The thallus of this species is brownish green and has a fibrous structure. Trichomes are direct, equivalent; the end of trichomes is temporarily thinned and bent. Uncontracted at cross walls, cells are 1.2-2.8 µm wide and 6-9 µm long, three times much longer then broad. There are three granules present on cross wall and the color of it is green. The shape of end cells is pointed, narrow and not globose.

15: Oscillatoria chalybea Mertens 1822

General characters:
Oscillatoria chalybea has a light blue green thallus, living trichomes which are straight throughout their length but tapering toward the apex and uncontracted at cross walls. On cross wall granules are absent, the movement of trichomes is rotate and forward. Cells 2-13 µm indiameter, 2-7 µm long, cells are 1/3 times much wider as compared to length. The end cells are thickened and uncapitate, calyptras is absent & gas vacuoles are present.

16: Oscillatoria chlorine Harvey1846

General characters:
The thallus of this species is yellowish green and thin. Trichomes are somewhat straight or bent, 3-9 µm wide, slightly contracted at the cross walls. There are no granules on cross walls, gas vacuoles are not present, calyptra is absent, and cells are smaller than broad, 5-9 µm broad and 2-8 µm long.

17: Phormidiumantarcticum West & G.S. West 1911: 292

General characters:
The thallus is filamentous, dark green and attached
through the lower side. The filaments are septate, pointed at the ends and forming a gelatinous stratum. It has thorn like margins which help floating in water. Sheath is present which is thin, colorless and partly diffluent. Trichomes are twisted, narrow in width and uncontracted at joints. Cells are 0.7 µm in diameter and 1.6 µm in length. The apices are straight, coiled, frequently thin and may be capitate or non capitate. The apical cells have a calyptra.

**18: Phormidium bohneri** Schmidle 1902: 59

**General characters:**

The thallus is filamentous, bluish green in color, the filaments are septate, slightly pointed at the ends, cylindrical and forming a leathery stratum. Sheath is present which is thin, colorless and partially diffluent. Trichomes are rounded, narrow in width and uncontracted at joints, non-granulated. Cells are 1.0-2.0 µm in diameter and 1.6-1.9 µm in length. The apices are straight, frequently thin and non-capitate. The apical cells are without a calyptra.

**19: Phormidium fragile** Gomont 1893: 163

**General characters:**

Its thallus is filamentous, light green in color, the filaments are septate, not pointed at the ends, cylindrical and forming a sticky stratum. Sheath is present which is thick and colorless. Trichomes are straight, wide and contracted at joints, thinned at the end, granulated. Cells are 1.8 µm in diameter and 1.6-3.0 µm in length, cross walls are granulated. The apices are straight, frequently thin and non-capitate.

**20: Rhizoclonium fontanum** Kützing 1843: 261

**General characters:**

Its filaments are slim and attached through the basal body. Cross wall present at some space from it and cells are cylindrical but the side walls are unevenly arranged. Cells are many times longer than broad, 45-48 µm broad and 130-389 µm long. Numerous nuclei are present; chloroplast is reticulate.

**21: Rhizoclonium implexum** (Dillwyn) Kützing 1845: 206

**General characters:**

Its filaments are slim, branched and branches arise from the adjacent cells of the parent filament. Cross wall present at some space from it and cells are cylindrical but the side walls are unevenly arranged. Cells are many times longer than broad, 45-48 µm broad and 130-389 µm long. Numerous nuclei are present; chloroplast is reticulate.

**22: Stigeoclonium elongatum** (Hassall) Kützing 1849: 355

**General characters:**

Its thallus is green and branched with long filaments; the branches become slowly tapered toward the end. Filaments are delicate, yellowish green, have a mucilaginous layer and attached through the rhizoids, width of filaments is 6.0-8.0 µm. The terminal cells modified into setae.

**23: Stigeoclonium lubricum** (Dillwyn) Kützing 1845: 198

**General characters:**

The thallus is dark green, plane, erect and having branched filaments. Filaments are also dark green, smooth, oily and forming a hairy tufts, 2-6 cm long and attached through rhizoids with main axes. Cells of main axes are 13-22 µm broad. The cell wall is thick, diameter of vegetative cells is 9-14 µm and length is 14-20 µm. The terminal cells are modified into setae.

**24: Stigeoclonium nanum** (Dillwyn) Kützing 1849: 354

**General characters:**

The thallus is yellowish green and having smaller filaments with erect branches arising from each cell alternately and become pointed toward the end. The diameter of cells of main axis is 10-12 µm which is larger than the cell of branches 5-10 µm, the length of cells is 10-20 µm similar throughout the branching system. Cells are colorless, globose, chloroplast is reticulate and later portion broadly filamentous or pseudoparenchymatous.

**25: Stigeoclonium tenue** (C. Agardh) Kützing 1843: 253

**General characters:**

The thallus is green to yellowish green, forming a fragile mat and having filaments with contrary branching & tapering ends. Branches are arising
irregularly from the main axis; filaments have erect and slender rhizoids. Cells are 10-13 µm wide, 3 to 6 times much longer then wide, 23-45 µm in length and cells are cylindrical, thin walled. The apices are hair like.

4. DISCUSSION
In the present study we identified a total number of 25 species and 8 genera of fresh water algae, 2 species were belonged to class Ulvophyceae, 2 Zygnemophyceae, 7 Chlorophyceae and remaining 14 were belonged to class Cyanophyceae from the Taxila zone. In which 9 species belonged to genus Oscillatoria which is related to the phylum Cyanobacteria, class Cyanophyceae, order Oscillatoriales and family Oscillatoriacea. Previously this genus was reported from Gujranwala, Jauharabad, Jhang, Kasure, Sargodha & the province of N.W.F.P. and Muzaffarabad, Azad Kashmir [10], Lahore, Sheikhupura and Sialkot Districts of the Punjab Province [11], from Golapara district, Assam, India [12]. From the remaining 16 species 4 belonged to genus Stigeocloniumwhichis related to phylum Chlorophyta, class Chlorophyceae, order Chaetophorales, family Chaetophoraceae. Previously this genus was studied from Gujranwala Districts and Lahore District during April 2004 and May 2005 [13] and 3 species belonged to genus Microsporawhichis related to phylum Chlorophyta, class Chlorophyceae, order Microsporales, family Microsporaceae. This genus was previously described from Switzerland and Lahore District. The remaining 9 species 3 belonged to genus Phormidiumwhichis related to phylum Cyanobacteria, class Cyanophyceae, order Oscillatoriales, family Phormidiaceae, this genus previously identified from India [14] and from Ongul Island, Vicinity and Antarctica [15] and 2 species belonged to genus Rhizoclonium which related to phylum Chlorophyta, class Ulvophyceae, order Cladophorales, family Cladophoraceae. This genus was previously reported from Sialkot and Kasure District [16] and 2 species belonged to genus Closterium which related to phylum Chlorophyta, class Zygmemophyceae, order Desmidiales, and family Closteriacea, this genus previously studied from Attock and Swat of NWFP and Lahore, Sialkot Districts of the Punjab province of Pakistan and Neelum Valley of Azad Kashmir [17] and 1 species belonged to genusChroococcus which related to phylum Cyanobacteria, class Cyanophyceae, order Chroococcales, family Chroococcaceae& remaining 1 species were belonged to genusNostoc which relatedtoPhylumCyanobacteria, classCyanophyceae, orderNostocales, familyNostocaceae and these two species previously reported from Ongul Island, Vicinity and Antarctica[18]. Both were the rarest genus in the study areas among the one species but the genus Oscillatoria was very common due to its large numbers of species. During the present study the species were found observed in Unicellular, unbranched filamentous, colonial, branched filamentous, pseudo filamentous and mesh like thallus& irregular forms. Seasonal variation of fresh water algae was also noticed, generally green & blue green algae were studied which breed in summer and spring season, but in summer they also survive. Water temperature is important, as the temperature increases the dissolved oxygen content decrease in water due to increase metabolism and respiration. High temperature has a direct effect on growth of algal species. In summer, the temperature was high up to 45 ºC with monsoon rainfall, tremendous Sunlight and sluggish water with pH 7.3; this was the most favorable environment for growth of algae. The rate of reproduction is very rapid of those species that reproduced in summer and rainy season and created a heavy mass on the surface of water. Their growth was most frequent in the aquatic medium especially in planktonic state as compared to the terrestrial environment. This is a first comprehensive taxonomical study from Taxila and its surrounding areas. These findings will be of great use to scientists in future who want to discover more and more about fresh water algae of Taxila.

5. REFERENCES
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Computation and Modeling of the Variability in Electron Concentration and Refractive Index for $F_2$ Layer at Pakistan Region

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Abstract: The ionosphere is electrically conducting region of the upper atmosphere, plays an important role in the ionospheric region on electromagnetic waves of 3 MHz to 30 MHz transmitted from ground station to reach to a receiving station. The low-frequency is limited by signals reflected from ionosphere and other range of frequencies are refracted from ionosphere layers depending upon time, height, season, temporal variations due to solar radiations, Sunspots and Earth magnetic field variations. In this communication the $F_2$ layer data recorded at SUPARCO Islamabad Ionosphere Station (SIIS) for the year 2005 has been used to compute useful ionosphere parameters in respect of ordinary critical frequency (3.04 to 8.29 MHz) at different altitudes of ionosphere with variation in ion composition of $F_2$ layer. The geographic location of SIIS is latitude 33.75°N and longitude 72.87°E. The critical frequency and height recorded on hourly basis have been used to compute the ionosphere parameters such as electron concentration and refractive index. The temporal estimation of parametric variability is determined, for estimation and modeling purposes standard statistical techniques have been preferred for regression and autocorrelation according to suitability of data trend/pattern. The aspect of study is useful in predicting and forecasting for sky wave communication. The result derived from study is useful for public, governmental and private sector organizations dealing with the business of radio wave communication in the region of Pakistan.

Keywords: Ionosphere, critical frequency, electron density, temporal variations, sunspot

1. INTRODUCTION

The ionosphere extends in the height from 70 to 600 Km above the sea level. Ionospheric regions are conventionally designated as C, D, E and F. Each region is characterized by degree of ionization that dependent on strength of solar radiations. The most important ionizing agents are ultraviolet and Alpha and Gama radiation from the Sun, as well as cosmic rays and meteors. The D, E and F layers show electron density peaks. The ionization is the greatest in the summer and day time, least in the winter and night. The Sunspot, a standard index of solar activity has influence on the radio flux density of ionosphere [1]. The ionosphere tends to be stratified, rather than regular, in its distribution. The existence of ionosphere as an electronically conducting region...
had been postulated earlier in 1883 to explain the daily variations in the geomagnetic field in 1902 correctly surmised that ionosphere contains free electrons and ions produced by solar ionizing radiation [3]. Research began in 1924 when Appleton and Barnett and Breit and Tuve measured the height of the ionosphere reflecting layers. From 1972 to 1975 NASA launched the AEROS and AEROS B satellites to study the F region [2]. The ionosphere is a region having refractive index < unity computed in terms of critical frequency and EM wave incident angle. In this study ground base recorded ionosphere data of year 2005 over Pakistan, Islamabad region is used to compute more important parameters which helped in establishing and presenting, sampling distribution, regression, correlation and modeling of recorded and investigated parameters.

2. THE F₂ LAYER

The computation of ionosphere electron concentration (N) resulted in varying refractive index (n) of F₂ layer and its effect on the long distance communication has been presented in the study. Any vertically launched waves can be reflected and oblique waves are progressively bent away from the vertical. The F layer extends 100 Km to 300 Km above the earth’s surface. This layer is maintained during day and night. During the daytime, the F region is bifurcated into F₁ and F₂ layers. The F₁ layer is the region extending at altitudes ranging from 150 Km to 210 Km which presents a regular stratification at moderate latitudes. The total electron concentration (TEC) in F₂ layer is greater than F₁ layer because of smaller electron loss. The electronic concentration in this layer vary $5 \times 10^{11}$ electron/m² during the night and $20 \times 10^{11}$ e/m² during the day and is heavily influenced by a) neutral winds, b) diffusion, c) by different other dynamic effects [2].

3. METHODOLOGY

The ionosphere, act as reflectors or absorbers to radio waves at frequencies below about 30 MHz. The following methodology to compute important ionosphere parameters, develop model, to apply statistical analysis such as regression, correlation, time series to investigate data seasonality/trends of the recorded and investigated parameters have been presented in this study with conclusion at the end. The computation and modeling of electron density and refraction index from the known recorded data for the (April-Dec) year 2005 over Pakistan ionosphere region is the main objective of this study. To understand parametric variability and its relationship the following valid mathematical tools have been used.

3.1 Electron Density and Critical Frequency

The density of electrons in the ionosphere also varies as a function of geomagnetic latitude, diurnal cycle, yearly cycle, and sunspot cycle. The reflection from the F₂ layer is the major factor in HF communications. The critical frequency is the limiting frequency at or below which a radio wave is reflected by an ionosphere layer at vertical incidence. The highest frequency returned to earth when radiated upward in the vertical direction. Its value is dependent on the composition of ionosphere i.e. strength of the electron concentration. For F₂ layer the ordinary critical frequency ($f_c$) is related to peak value of (N) given in Eq-(1). The ionosphere conditions change from hour to hour, day to day, month to month, season to season and year to year therefore, the $f_c$ also changes constantly. The recorded hourly maximum and minimum critical frequency is 8.28 MHz and 3.03 MHz respectively. The peak value of electron density of F₂ layer is calculated in respect of measured ordinary critical frequency, the expression in Eq-(2) postulated by Anderson and Matsushita [1&3] in 1974.

$$f_c = \sqrt{80.8N} \equiv 9 \sqrt{N(\text{max})}$$

$$N(\text{max}) = 1.24 \times 10^4 f_c^2 \text{MHz e/cm}^3$$

The computed electron concentration maximum value $8.5166 \times 10^{11}$ and minimum value are $1.1441 \times 10^{11}$ with mean of $3.1829 \times 10^{11}$ having standard deviation of $9.9092 \times 10^{10}$ electron/cm³. For the F₂ layer the extraordinary critical frequencies, which exist
because of the birefringence caused by the Earth’s magnetic field is determined using extra ordinary critical frequency \((f_x)\) is determined using gyro-frequency \((f_g)\) given in Eq-(3). The gyro-frequency of a charged particle is its rate of gyration in a magnetic field. If the magnetic induction \((B)\) is gradually increased, the gyration frequency is increased in proportion. For a magnetic field \((B)\) of 0.5 gauss \((0.5 \times 10^{-4} \text{ Wb/m}^2)\) the gyro-frequency for Islamabad region is calculated [4]. The electron count in respect of extra-ordinary critical frequency is calculated with the help of Eq-(4).

\[
\begin{align*}
    f_g &= \frac{a q}{2 \pi m} \equiv 1.4 \text{ MHz} \\
    f_x &= f_0 + \frac{f_g}{2} \text{ MHz} \\
    N_x(\text{max}) &= 1.24 \times 10^4 (f_x^2) \text{ e/cm}^3
\end{align*}
\] (3)

3.2 Refraction in Ionosphere

The ionosphere is weak plasma. A vertically launched waves can be reflected and an oblique waves are progressively bent away from the vertical. The amount of refraction depends on three main factors: (a) the density of ionization of the layer, (b) the frequency of the radio wave, and (c) the angle at which the wave enters the layer. The dielectric approach for ionosphere as proposed by Larmor in 1924 is appropriate for most radio frequencies; the absorption is relatively small inside the ionosphere, and the wave is returned the ground by gradual refraction [4].

Total refraction occurs when the collision frequency of the ionosphere is less than the radio frequency and if the electron density in the ionosphere is great enough. The velocity of an electromagnetic wave in vacuum is equal to velocity of light but in ionosphere medium it is given by \(v = \frac{c}{n}\) where \(n\) is refractive index of ionosphere medium rather than property of wave. In the simplified form refractive index mentioned in Eq. (5) of ionosphere is given by Appleton-Hartee expression [1, 5].

\[
n^2 = 1 - \frac{X(1-X)}{(1-X)^2 + \frac{1}{2} X^4 + \frac{1}{4} X^2} \frac{1}{Y_L} \frac{1}{Y_T}
\] (5)

where,

\[
X = \frac{N e^2}{\varepsilon_0 m_o a^2}, \quad Y_L = \frac{e B_L}{m_o} \text{ and } Y_T = \frac{e B_T}{m_o}
\]

If \(\theta\) is the angle between the propagation direction and the geomagnetic field, then \(\omega_L = \omega_g \cos \theta\) and \(\omega_T = \omega_g \sin \theta\). In the simplest case, when there are no collisions \((Z = 0)\) and the magnetic field is neglected \((Y_L = Y_T = 0)\) the Eq-(5) becomes [4];

\[
n^2 = 1 - X = 1 - \frac{\omega_N^2}{\omega^2} = 1 - \frac{Ne^2}{\varepsilon_0 m_o a^2}
\] (6)

If the magnetic field is included the refractive index becomes double valued. The two waves are called the characteristic waves, the upper sign giving the so-called ordinary wave, and the lower sign the extraordinary wave. When collisions are significant \((Z \neq 0)\) the refractive index is complex. The ionosphere is a nonmagnetic medium the expression (7) expresses the dielectric constant \((k)\):

\[
n^2 = \frac{c^2}{v^2} = \mu_0 \varepsilon_0 \text{ and } \varepsilon_0 = \varepsilon / \varepsilon_0 = k
\] (7)

In our case the variation in the computed values of refractive index is 0.9525 to 0.9485 with mean 0.9502 and a least standard deviation of 0.0005 subject to bending of EM wave in \(F_2\) and \(F\) layers which finally helps in establishing long distance communication. It is the angle above which the signal will not be reflected enough to return to earth. It has been observed that by lowering the radiation angle from the exact vertical direction allows the wave to travel longer through the ionosphere layers. It is also seen that signals above the critical angle penetrate the ionosphere layers while below this angle the wave returns to earth. The critical angle for radio waves depends on the layer electron density and the wave length of the signal. As the frequency of a radio wave is increased, the critical angle must be reduced for refraction to occur. The critical frequency which is proportional to:

\[
f_{\text{crit}} = f_c \sec \theta
\] (8)
4. EXPLORATORY DATA ANALYSIS

In this study hourly monthly-median values of the critical frequency of the daytime $F_2$ layer and the night-time $F$ region, measured at mid-latitude at Islamabad region are used. The exploratory data analysis is an important part of statistical analysis. EDA approach relies heavily on graphical techniques i.e. plotting of histogram for representation of distribution with single quantitative variable. The continuous envelope provides the hypothetical limit of samples. In this particular study, the sampling distribution of critical frequency, electron concentration and refractive index is witnessed in histogram plots shown in Figs. 1 to 3. The distributions are symmetrical and tend to show Gaussian normal distribution for sample value $S= 153$. The variability in ionosphere chemistry due to change in solar radiation, $(N)$ is subject to change in $(n)$ and to put impact on the long distance communication at Pakistan region has been investigated and presented.

4.1 Regression Analysis

It has been observed that the correlation between the parameters can be evaluated using scatter plots which are useful diagnostic tool for investigating association between two variables. The bivariate distribution presented in scatter plot shown in Fig. 4 display fairly high degree of positive correlation between ordinary critical frequency (recorded by DG 256 Ionosphere Receiver installed at SUPARCO Ionosphere Station at Islamabad) and electron concentration of $F_2$ layer. Scatter plots are useful diagnostic tool to investigate association between two variables. The bivariate distribution presented in scatter plot shown in Fig. 4 display fairly high degree of positive correlation between ordinary critical frequency and electron concentration of $F_2$ layer. A straight line having intercept equals to $-3.5777 \times 10^{11}$ and slope of line $= 1.3484 \times 10^{11}$ show comfortably fits through our sample data consisting of 153 observations. The Pearson’s statistic, $r = 0.9925$ is very close to unity. This shows strong relationship i.e. changes in one variable with changes in the second variables [6]. The regression fit equation is;

$$N = -3.5777 \times 10^{11} + 1.3484 \times 10^{11} f_c$$  \hspace{2cm} (9)

The relationship between refractive index and critical frequency show a strong negative correlation, $r = -0.9739$ with two outliers, a straight line with intercept of 0.9537 and slope equals to - 0.0007, witnessed comfortably fits through the computed data values. This is translated as for decreasing values of refractive index the critical frequency increased as shown in Fig. 5. The regression line equation is;

$$n = 0.9537 - 0.0007 f_c$$ \hspace{2cm} (10)

The regression between $(N)$ and $(n)$ is an approximate linear relationship but it reveals a negative correlation statistical condition, $r = -0.9399$ referred to as hetero-scedasticity i.e. non-constant variation in data points. The presence of outliers is due to either measurement error or recording equipment malfunctioning. The regression line equation is;

$$n = 0.9518 - 5.0118 \times 10^{-15} N$$ \hspace{2cm} (11)

The coefficient of correlation $(r)$, measure of the closeness of a fit in the relative sense, coefficient of determinant $(r^2)$ tells the process of variation of the parameters. The error $(P)$ and for significant correlation covariance $< 6$ (coefficient of correlation). The Pearson’s correlation values in each case are mentioned in the Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>(r)</th>
<th>(r^2)</th>
<th>(P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N$ Vs $f_c$</td>
<td>0.9925</td>
<td>0.9850</td>
<td>0.0000</td>
</tr>
<tr>
<td>$n$ Vs $f_c$</td>
<td>-0.9725</td>
<td>0.9485</td>
<td>0.0000</td>
</tr>
<tr>
<td>$n$ Vs $N$</td>
<td>-0.9399</td>
<td>0.8834</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

4.2 Normal Probability Plot

Diurnal daily and monthly distributions of ion concentration are presented and the relative role of the solar radiation has been evaluated. The normal probability plot is a special case of the probability plot. The points that fall on the fitted straight line indicate a normal distribution. The Fig. 7 form a nearly linear pattern indicates that the normal distribution is a good model for the refractive index. Departures from the straight line indicate
Fig. 1. Histogram of observed critical frequency with normal curve.

Fig. 2. Histogram of observed electron concentration with normal curve.
Fig. 3. Histogram of observed refractive index with normal curve.

Fig. 4. Scatter plot of electron concentration and critical frequency.
Fig. 5. Scatter plot of refractive index and critical frequency.

Fig. 6. Regression between refractive index and electron concentration.
Fig. 7. Normal probability plot of refractive index.

Fig. 8. Normal probability plot of electron concentration.
Variability in Electron Concentration and Refractive Index for $F_2$ Layer

departures from normality. In Fig. 8: the fitted line indicates departure of data from extremes. It is evident that the data do not follow normal distribution. A convex curve illustrate that the distribution is skewed to the left [7].

4.3 Inferential Aspects

Time series data have a natural temporal ordering. The time domain approach of time series analysis suggests correlation between adjacent points in time is best investigated in terms of a dependence of the current value on the past values. It also focuses on modeling some future value of a time series as parametric function of the current and previous values [8]. In this communication seasonal pattern with periodic behavior of variation in electron concentration and refractive index against time is shown in Figs. 9 and 10, show variations reflecting increase and decrease of data in the ionosphere of $F_2$ layer in day time and F during night over Pakistan region.

4.4 Smoothing

Smoothing data removes random variation and shows trends and cyclic components. This technique, when properly applied, reveals more clearly the underlying trend, seasonal and cyclic components. Non-stationarity present in time series plots are removed by differencing the data or by fitting some type of trend curve. The time series plots indicate a falling trend for electron concentration and a rising trend for refractive index under discussion. A visual inspection of these plots indicates that a simple linear fit is sufficient to remove the trend but the variance (amplitude) is still varying with time. The residual plots along with actual time series and smoothed series for fitting with linear trend curve for both parameters is shown separately [8]. The single exponential smoothing of TEC is computed with $\alpha = 0.3$ for minimum mean % error (MPE) and mean absolute % error (MAPE) with least residual show a fairly stable model as shown in Fig. 11.

$$F_{t+1} = \alpha Y_t + (1 - \alpha ) F_t$$  

\[0 < \alpha \leq 1 \text{ } t > 0\]  

The single exponential smoothing of TEC is computed with $\alpha = 0.3$ for minimum mean % error (MPE) and mean absolute % error (MAPE) with least residual show a fairly stable model as shown in Fig. 11.

<table>
<thead>
<tr>
<th>Table 2. The summary of error.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Summary of Error</strong></td>
</tr>
<tr>
<td>Mean Error</td>
</tr>
<tr>
<td>Mean Absolute Error</td>
</tr>
<tr>
<td>Sum of Squares</td>
</tr>
<tr>
<td>Mean Squares</td>
</tr>
<tr>
<td>Mean % Error</td>
</tr>
<tr>
<td>Mean Absolute % Error</td>
</tr>
</tbody>
</table>

The smoothing of Refractive Index is computed with $\alpha = 0.25$ for minimum mean % error (MPE) and mean absolute % error (MAPE) with least residual as shown in Fig. 12. The summary of errors for both parameters is mentioned in Table 2. The residual analysis determined by single exponential smoothing shows a sufficiently high degree of correlation and a stable model. The Bootstrapping forecast technique explained in Eq-(12) is used to forecast the parameter under study. The forecast values with single exponential smoothing for TEC and refractive index are computed in Eqs-(14) & (15) respectively using model Eq- (13).

$$F_{t+1} = F_t + \alpha (X_t - F_t ) = F_t + \alpha (e_t )$$  

\[F_{154} = (0.3) Y_{153} + (0.7)F_{153} = 2.88873\times 10^{11}\]  

\[F_{154} = (0.25) Y_{153} + (0.75) F_{153} = 0.950378\]  

4.5 Model Strategies

There are many methods used to model and forecast time series. The most commonly used model fitting include Box-Jenkins (1976-1996)
Fig. 9. Time series plot of electron concentration.

Fig. 10. Time series plot of refractive index.
Variability in Electron Concentration and Refractive Index for $F_2$ Layer

**Fig. 11.** Electron concentration-actual and exponential smoothing values.

**Fig. 12.** Refractive index-actual and exponential smoothing values.
Fig. 13. Forecasting graph of electron concentration.

Fig. 14. Illustration of autocorrelation function for TEC.
ARIMA models to handle time-correlated modeling and forecasting. A general ARIMA (p,d,q) model defines autoregressive order, difference and moving average respectively. Autoregressive process is a stochastic difference equation, a mathematical model in which the current value of a series is linearly related to its past values, plus an additive stochastic shock [9&10]. To estimate the impact of solar radiation on TEC and refractive index of F_2 layer at day time and F layer in night, an autoregressive of order one {AR (1)} general model as given in expression (16). A developed stochastic model for ionosphere layer is used to estimate the TEC and refractive index over Islamabad ionosphere region.

\[ X_t = \varphi X_{t-1} + \varepsilon_t \quad (16) \]

\( \varepsilon_t \): Source of randomness and is called white noise.

\( \varphi \): Autoregressive Coefficient

The general model AR (1,0,0), for TEC, the estimates of autoregressive parameters is 0.95556, the standard error 0.02470, the value of t-statistic 38.68 of 153 and lower-95% confidence, upper-95% confidence are 0.906767 and 1.004361 for probability < 0.05. In case of refractive index autoregressive parameter is 0.999950 where the standard error is zero, see Table 3.

### Table 3. Parametric description of F_2 layer.

<table>
<thead>
<tr>
<th>Variable</th>
<th>TEC-P(1)</th>
<th>n – P(1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient</td>
<td>0.95556</td>
<td>0.99995</td>
</tr>
<tr>
<td>Std Err.</td>
<td>0.02470</td>
<td>0.00</td>
</tr>
<tr>
<td>t-statistics</td>
<td>38.680</td>
<td>-</td>
</tr>
<tr>
<td>P</td>
<td>0.00</td>
<td>-</td>
</tr>
<tr>
<td>Low 95% Confidence</td>
<td>0.906767</td>
<td>-</td>
</tr>
<tr>
<td>Up 95% Confidence</td>
<td>1.004361</td>
<td>-</td>
</tr>
</tbody>
</table>

4.6 Forecasting

In the time series of Figs. 9 & 10 follow a repeating pattern, \( X_t \) is highly correlated with \( X_{t-1} \). To create time series model such that the error between the predicted value of the variable and the actual value is as small as possible. The model use lag values of the TEC are used as predictor variables. The TEC forecast value is calculated using Eq-(16), \( X_t = 0.95556 \times 2.8376 \times 10^{11} + 0.0247 = 2.71149 \times 10^{11} \) also mentioned in Table 4. The time series for total electron density forecast is presented in Fig. 13.

### Table 4. Forecast values of TEC of F_2 layer.

<table>
<thead>
<tr>
<th>Forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td>154 2.837691E+11</td>
</tr>
<tr>
<td>155 2.711596E+11</td>
</tr>
<tr>
<td>156 2.591103E+11</td>
</tr>
<tr>
<td>157 2.475965E+11</td>
</tr>
<tr>
<td>158 2.365944E+11</td>
</tr>
<tr>
<td>159 2.260811E+11</td>
</tr>
<tr>
<td>160 2.160350E+11</td>
</tr>
<tr>
<td>161 2.064353E+11</td>
</tr>
<tr>
<td>162 1.972621E+11</td>
</tr>
<tr>
<td>163 1.884966E+11</td>
</tr>
</tbody>
</table>

An autocorrelation is the correlation between the target variable, TEC and lag values for the TEC. Correlation values range from -1 to +1 show that the two variables move together perfectly. In the presentation the estimated correlation between \( i \)th observation and the \((i + m)\)th observation on Y-axis vs the lag number on the X-axis [8]. On examining autocorrelation illustrated in Fig. 14 the highest autocorrelation is + 0.533 which occurs with a lag 4. Hence we desire to be sure to include lag values up to 4 when building the model. The second column of the autocorrelation indicates the standard error of the autocorrelation. The autocorrelation bars indicates positive significant autocorrelations occurred for lags 1 to 15. The statistical significance (Q statistical) is mentioned on the right hand side.
The partial autocorrelation is the autocorrelation of time series observations separated by a lag of k time units with the effects of the intervening observations disqualified [9]. The partial autocorrelation plot is shown in Fig. 15 present statistical significance for 1 to 4, 8 and all other lags are 95% confidence interval bands.

5. RESULTS AND CONCLUSION

The presence of ionosphere and change in its characteristics with time is a potential source of radio wave communication. This communication has described physical behavior of ionosphere at Pakistan upper atmosphere region. The result of the processing of radio sounding data determines the statistical values mentioned in Tables 1 to 4 for realization of varying ion concentration and radio refractivity during day and night for long distance communication via ionosphere. The trends and the data pattern variability are also visible in graphical representations and discussed under relevant sub headings.

The Exploratory Data Analysis carried out and the models have been developed, has provided a comprehensive statistical description of the process. It is concluded that methodology adapted is suitable in a sense that only input required are the measured values of critical frequency and altitude for the F₂ layer. It is witnessed that the main advantage of this method is its simplicity. The computed values of parameters are found reasonably accurate. It is seen that the ARIMA (1) is found suitable for predicting and finding forecast for ionosphere parameter under study. The variability in ionosphere electron concentration (N) resulted in varying refractive index (n) and its effect on the long distance communication has been observed in this study.

6. ACKNOWLEDGEMENTS

The authors are grateful to the officials of Pakistan Space & Upper Atmosphere Research Commission (SUPARCO) for provision of ionosphere data. The data
Variability in Electron Concentration and Refractive Index for $F_2$ Layer

helped us in carrying out this research work and producing this publication. This work enables the effective radio communication with respect to the radio wave bending.

7. REFERENCES


Wind Speed Analysis of Some Coastal Areas near Karachi

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Abstract: This communication attempts to analyze Karachi coastal area (Paradise Point 24.84º E, 66.77º N) for an understanding of underlying probability distribution. It has been found that at this site the annual wind speed at a height of 30 meters remains very close to 7 m/s whereas at a height of 61 meters the wind speed reaches to 9 m/s. Moreover, the wind mostly remains directed towards southwest. Furthermore, the annual average wind speed follows Weibull distribution and the annual average wind speed goes on increasing with the passage of time. Maximum energy together with the energy density for different values of the wind mill blade diameters is also calculated. Our analysis shows that the wind speed is increasing as a consequence of global climate change. Though the global climate change has created many threats to the humanity by influencing the local urban microclimate but the positive aspect of this finding is that the increase in wind speed will increase the feasibility and economic viability of the construction of wind farms near Karachi coast and offshore. Of course these calculations will be useful for urban and energy planners.

Keywords: Global warming, Karachi Nuclear Power Complex (KNPC), maximum likelihood (ML), cumulative distribution function (cdf)

1. INTRODUCTION

Probable effects of the link between human induced global warming and climate change is not yet fully understood [1]. However, in [2] it is shown that in addition to its other consequences the global climate change has influenced the local urban microclimate adversely. For example is the case of ozone layer depletion. Like the rest of the world it has statistically significant impacts on Arabian Sea and the Pakistan air space [3]. Global warming is also found responsible for the expansion of the seawater volume. Significant links of eleven years sun spots cycles with climatic phenomena particularly with ozone layer depletion over arctic region have also been detected [4]. Moreover, the frequency of occurrence of high magnitude earthquake is affecting the magnetic field around the earth which in turn is accelerating global warming rate [5]. Persistency analysis performed on 120 years Arabian Sea cyclone data also shows a positive trend in cyclone frequency [6]. The significant impact of global climate change has been observed in North America, East Asia and the Caribbean [7-10] also.

We know that wind power is a clean, renewable source of energy, which produces no greenhouse gases. Wind power thus appearing a CO₂ free source for energy generation. Current estimates show that one modern wind turbine can save over 4,000 metric ton of CO₂ emissions annually. It also reveals that present wind turbine is designed to operate for more than 20 years, produces electricity for 70 – 85 % of the time (depending on available wind speed), and at the end of its working life, the area can be restored at minimum financial costs. Wind energy is a form of development, which is reversible – in contrast to conventional power stations [11].

Pakistan coast is about 1120 km long [12]. In most parts of our country the wind speed is relatively
low. However, there are various places where wind power can be effectively generated. The potential areas for the installation of windmills are coastal areas and some hilly regions in the country [13]. This paper analyses the wind data collected at heights of 10, 30 and 61 meters at Karachi Nuclear Power Complex (KNPC), near Paradise Point, Karachi. Preliminary analyses show that the wind resource fluctuates greatly depending on the season, which suggests that using it as the sole source of energy would likely be impractical. The best estimate of wind power potential can be made with the help of long-term wind record at the site where the turbines are to be installed, but unfortunately this information is rarely available. However, a dataset of two hours average wind speed for one year (1995) reveal that the annual mean wind speed in the vicinity of KNPC is about 7 m/s. Hourly averaged data (collected in 2002 and 2003) at height of 61 meters, also show that the wind speed remains close to 9 m/s. This communication attempts to estimate the wind speeds in the last decade at the coast of Karachi, taking Paradise Point as a case study. It uses Weibull distribution as the underlying distribution of wind data as revealed by Histograms of wind data. It also tries to estimate the wind energy potential at this site. The wind data and modeling is performed in Section 2.1. Details of assessment procedure and mathematical descriptions are provided in Section 3. Section 4 depicts important outcomes of the analysis performed in the previous section. Finally, Section 5 concludes the paper.

2. MATERIAL AND METHODS

Wind Data analysis is performed with the help of Weibull Distribution parameters. Weibull Distribution parameters are estimated with the help of Direct Method of Parameters Estimation and Maximum Likelihood Estimation method. Matlab is used for performing the calculation. Histogram is used to confirm the analysis regarding wind speed and frequency. Rose Diagrams are used to study the wind direction profile.

2.1 Wind Data and Analysis Approach

As discussed in the introduction, the wind speed measurements were made at KNPC meteorological tower, at the heights of 10, 30 and 61 meters. The site of the measurements is located very close to the Paradise Point coast of Karachi. The results from the full year analysis are used as the base for energy production estimates. As for as the wind direction is concerned, we can say that wind at KNPC site mostly blows in the southwest direction (see Fig. 1). However, in the months of October, November, December, January, February and March, the wind directions show high degree of fluctuations and direction of wind seems to cover 220 to 330 degrees as depicted in Fig. 2.

3. ESTIMATION OF WEIBULL DISTRIBUTION PARAMETERS

Before going into the details of distribution parameters estimation techniques, we briefly outline the data analysis approach adopted in this paper. Weibull probability distribution appropriately models coastal wind data of Karachi, Sindh [14]. Histograms (see Figs. 3-5) also reveal that Weibull probability distribution is adequate for the modeling of Karachi coast wind data. The Weibull distribution function has two parameters: the shape factor ($\beta$) and the scale factor ($\eta$). We obtain these parameters using two different parameter estimation methods (direct and maximum likelihood estimation). After estimating the Weibull distribution parameters, we compute the site average wind speeds. To calculate the available energy and wind power density at the site we use the Weibull parameters, estimated using the maximum likelihood (ML) function as this method gives more precise results [15]. Then, we calculate the maximum energy and the energy density, in kWh/m$^2$, that can be produced or extracted by a wind turbine at the site.

The Weibull probability density function (pdf) is defined as follows:

$$f(x) = \frac{\beta}{\eta} \left( \frac{x}{\eta} \right)^{\beta-1} e^{-\left( \frac{x}{\eta} \right)^{\beta}},$$

$$x \geq 0, \beta > 1, \eta > 0$$

The parameter $\beta$ is known as the shape factor, and the parameter $\eta$ is known as the scale factor. In wind probability analysis, the variable $x$ is
Fig. 1 (a-f). Wind rose diagrams for the months from April to September 2002.
Fig. 2 (a-f). Wind rose diagrams for the months from Oct to Dec, 2002, and from Jan to March 2003.
Fig. 3. Annual wind speed data (taken at 30 meters height) histogram for the year 1995. Two hourly data gives a wind velocity of 6.7 m/s.

Fig 4. Annual wind speed data (taken at 61 meters height) histogram for the year 2002.
replaced by the wind speeds $v$. A Weibull pdf with a shape factor bigger than one reflects the shape of a bell. The scale factor defines that where the bulk of the distribution lies and how stretched out the distribution is. The cumulative distribution function (cdf) of (2.1) is obtained by the integration of pdf, as shown by (2.2).

$$F(x) = 1 - e^{-\frac{x}{\eta}},$$

$x \geq 0$, $\beta > 1$, $\eta > 0$ \hfill (2.2)

In wind engineering, the shape factor is referred to as $k$ parameter, whereas scale factor is known as $c$ parameter (also known as velocity parameter). Shape factor gives the wind characteristic at a location as shown in Table 1.

**Table 1.** Typical shape factor values.

<table>
<thead>
<tr>
<th>Type of Winds</th>
<th>Shape Factor (k)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inland winds</td>
<td>1.5 to 2.5</td>
</tr>
<tr>
<td>Coastal winds</td>
<td>2.5 to 3.5</td>
</tr>
<tr>
<td>Trade winds</td>
<td>3 to 4</td>
</tr>
</tbody>
</table>

Inland winds represent the winds at inland locations. Similarly, coastal winds are present at coastal locations of the area under study. The trade winds (also called trades) are the prevailing pattern of easterly surface winds found in the tropics near the Earth's equator. The trade winds blow predominantly from the northeast in the Northern Hemisphere and from the southeast in the Southern Hemisphere. Next, we define parameter estimation methods.

### 3.1 Direct Method of Parameters Estimation

To obtain crude estimates of shape factor, $\beta$, and scale factor, $\eta$, one can utilize the following formulae.

$$\beta = \left(\frac{\sigma}{\bar{v}}\right)^{-1.086}$$ \hfill (3.1)

where, $\sigma = \frac{\sum_{i=1}^{N}(v_i - \bar{v})^2}{N - 1}$ \hfill (3.2)

$$\bar{v} = \frac{\sum_{i=1}^{N}v_i}{N}$$ \hfill (3.3)

$$\eta = \frac{\Gamma\left(1 + \frac{1}{\beta}\right)}{\bar{v}}$$ \hfill (3.4)

---

**Wind speed**

Fig. 5. Annual wind speed data (hourly averaged taken at 61 meters height) histogram for the year 2003.
The above formulae, (3.1) and (3.4), in general, provide accuracy up to one decimal place. As we know that the maximum likelihood estimation (MLE) method give the most precise values of distribution parameters, therefore, these values are obtained by using MATLAB command `wblfit(data)`, and the two values are compared.

### 3.2 Maximum Likelihood Estimation

This section gives some details of Weibull distribution parameters estimation by Maximum Likelihood Estimation (MLE) method. There are several techniques of Weibull distribution parameter estimation. The parameter $\beta$ is calculated using the following relation:

$$B = \frac{\sum_{i=1}^{N} (\ln x_i) Y_i - \left( \frac{\sum_{i=1}^{N} \ln x_i}{N} \right) \left( \frac{\sum_{i=1}^{N} Y_i}{N} \right)}{\sum_{i=1}^{N} (\ln x_i)^2 - \left( \frac{\sum_{i=1}^{N} \ln x_i}{N} \right)^2}$$  \hspace{1cm} (3.5)

where $Y = \ln \left(- \ln (1 - F(x)) \right)$

The parameter $a$ given below is used to estimate $\eta$ the second parameter of Weibull distribution.

$$a = \frac{\sum_{i=1}^{N} Y_i}{N} - \beta \left( \frac{\sum_{i=1}^{N} \ln x_i}{N} \right)$$ \hspace{1cm} (3.6)

where $\eta$ is obtained by

$$\eta = e^{-\frac{a}{\beta}}$$ \hspace{1cm} (3.7)

Table 2 summarizes the Weibull distribution parameters estimated by MLE method using MATLAB.

**Table 2.** Wind speed at KNPC site at 10, 30 and 61 meters.

<table>
<thead>
<tr>
<th>Year</th>
<th>1995 (10 m)</th>
<th>1995 (30 m)</th>
<th>2002 (61 m)</th>
<th>2003 (61 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Speed</td>
<td>5.9 m/s</td>
<td>6.8 m/s</td>
<td>8.6 m/s</td>
<td>9.6 m/s</td>
</tr>
<tr>
<td>Weibull pdf Parameters</td>
<td>$c = 6.6$</td>
<td>$c = 7.5$</td>
<td>$c = 9.6$</td>
<td>$c = 10.5$</td>
</tr>
<tr>
<td>$k = 3.3$</td>
<td>$k = 2.3$</td>
<td>$k = 2.1$</td>
<td>$k = 2.5$</td>
<td></td>
</tr>
</tbody>
</table>

Using above values of $k$ (shape parameter) and $c$ (scale parameter), we can obtain variance and mean of wind speed data using the following relationships.

**Variance:** $\sigma^2 = c^2 \left[ \gamma(1+2/k) - (\gamma(1+1/k))^2 \right]$,  \hspace{1cm} (3.8)

and

**Mean:** $\mu = c \cdot \gamma(1+1/k)$.

**Wind Power Formulae:**

In general, the following equation is used for energy recovery from the wind:

$$P = \frac{C_p \mu A \rho V^3}{2}$$ \hspace{1cm} (3.8)

where $P$ is power in watts, $C_p$ is the Coefficient of performance, $\mu$ is Conversion efficiency, $A$ is the blade swept area (m$^2$), $\rho$ is the density of air (1.225 kg/m$^3$ for dry air at sea level), $V$ is the wind speed (m/s).

One can only increase the available power in low winds by sweeping a larger area with the blades and that’s the second key concept obtained from this formula [16]. The available power increases by a factor of 4 by doubling the diameter of the blades. Similarly, the absolute maximum that can be extracted from the available power is 59.3%. One can also utilize shape parameter, $k$, to estimate the average power using the following formula:

$$\bar{P} = \frac{\rho A \left( \frac{V}{\mu} \right)^3}{2 \left[ \gamma(1+\frac{1}{k}) \right]^3}$$ \hspace{1cm} (3.9)

**Rated and cut-in wind velocities are related by the following expression:**

$$V_{cr} = (0.15)^\frac{1}{3} V_r$$ \hspace{1cm} (3.10)

Rated wind speed for slow and fast wind machines are respectively 5.3 m/s and 8.5 m/s. Similarly, the cut-in speeds for these machines are 2.5 m/s and 3.5 m/s respectively.
For a three-bladed horizontal fast wind machine with blade diameters of 5 to 10 m, the compact formula of (3.11) [17] can be utilized to estimate the maximum power.

\[ P = (0.20)D^2V^3 \]  

(3.11)

Where, \( P \) is in watts and \( D \) (diameter of blade) in meters.

### 3.3 Wind Speed Histograms

Histograms can be utilized to estimate frequency of a particular wind speed in a month or year. These histograms show that, more or less, 70 - 80% of the time the wind speed remains higher than 6 m/s at 61 meters height. The shapes of the histograms also suggest that the underlying distribution of annual wind speed at Paradise Point is a Weibull probability distribution.

### 4. RESULTS AND DISCUSSION

Here we discuss the results of wind data analysis obtained in Section 3. The measurements were taken in the years 1995, 2002, and 2003. Table.1 gives typical values of shape parameter at different geological locations. In Table.2, wind speeds at KNPC site at 10, 30 and 61 meters are shown. In addition, it also mentions the estimated parameters of Weibull distribution. It is clear that the wind speed for the year 2003 seems to be on higher side and is close to 8.8 m/s. On the average, we can say that wind speed at 61 meters height is approximately 9 m/s. Overall wind energy potential is reasonable at this height at KNPC site. So, we can safely say that small or medium size windmills can be installed in the vicinity of KNPC. In general, it is better to collect ten minutes (or five minutes) average wind speed data for 10-20 years. This will reveal more insights of the performed analysis. In future analysis, more data will be procured and dynamical analysis approach will be employed to explore further insights of the fluctuating pattern of coastal wind speed at the site under consideration. This will in turn give better estimates of the impact of global climate change on local climate parameters. Table3 gives power output values for fast wind machines with different blade diameters.

<table>
<thead>
<tr>
<th>Year</th>
<th>1995 (10 m)</th>
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<td>8.6 m/s</td>
<td>9.6 m/s</td>
</tr>
<tr>
<td>D = 5m</td>
<td>1.03 kW</td>
<td>1.60 kW</td>
<td>3.20 kW</td>
<td>4.42 kW</td>
</tr>
<tr>
<td>D = 10m</td>
<td>4.11 kW</td>
<td>6.30 kW</td>
<td>12.70 kW</td>
<td>17.70 kW</td>
</tr>
<tr>
<td>D = 30m</td>
<td>36.97 kW</td>
<td>56.60 kW</td>
<td>114.50 kW</td>
<td>159.25 kW</td>
</tr>
</tbody>
</table>

### 5. SUMMARY AND CONCLUSIONS

This communication attempted to estimate the wind speeds in the last decade at the Paradise Point coast of Karachi. It used Weibull distribution as the underlying distribution of wind data as revealed by Histograms of wind data. It also tried to estimate the wind energy potential at this site. Different mathematical formulae have been explained for the estimation of distribution parameters. MATLAB program was utilized to carry out distribution parameters estimation. In addition, MATLAB program was also used to obtain rose plot to represent wind direction at the site. Our conclusions are:

a) Wind speed data at Paradise Point follow Weibull probability distribution.

b) Average annual wind speed remains above 7 m/s at 30 meters height, and 9 m/s at 61 meters height. Most of the time wind remains in the direction covering 220 to 330 degrees.

c) It has been observed that the wind speeds in the winter are very low and there is no consistency in the wind direction.

d) As global climate change is affecting the natural wind pattern all over the world [18- 19], so, in future a better analysis for exploring the wind dynamics at the site under consideration will be possible only if more data can be procured.

e) Since wind speed is increasing as a consequence of global climate change, therefore, in near future wind farm near Karachi coast as well as offshore wind farm will be feasible and economically viable. Finally, the analysis done in the paper seems to be basic. Nevertheless, it
is hoped that the study performed will be useful for further analysis in the wind energy discipline by taking larger data sets and economic analysis into account.

6. ACKNOWLEDGEMENTS

We thank the Director, Karachi Institute Power Engineering, for his encouragement and support in this study.

7. REFERENCES

The following eminent scientists were elected Fellows of the Pakistan Academy of Sciences during 2013:

Prof. Dr. Amin Badshah

Prof. Dr. Amin Badshah earned MSc in chemistry in 1984, joined as a lecturer in Gomal University and was promoted to Assistant Professor after earning PhD degree in 1994. In 2002, he joined Quaid-i-Azam University (QAU), Islamabad as Associate Professor and was promoted as Professor in 2005. Presently, he is a Tenured Professor and Chairman, Department of Chemistry, QAU, Islamabad.

Dr. Amin Badshah has more than 195 publications in international peer-reviewed journals. Total impact factor and citations of these papers are 219.6 and 1327, respectively. He has availed postdoctoral fellowships MS&T and DAAD.

After joining QAU, Dr. Amin Badshah has produced 13 PhD and 35 MPhil. One postdoctoral, 10 PhD and 5 MPhil students are currently working under his supervision. A couple of PhD students from Gomal University and three MPhil students from Hazara University have completed their research under his co-supervision. He has earned several research grants from Higher Education Commission (HEC) and the QAU Research Fund. In recognition of his scientific contributions, he has been awarded Research Productivity Award regularly by the Pakistan Council for Science & Technology. Dr Amin Badsha is Fellow of Chemical Society and Associate Editor of Journal of the Chemical Society of Pakistan. He has served as member of QAU Syndicate and Chairman of the University Discipline Committee. He is also a member of the Board of Advanced Studies & Research for the last six years.

In recognition of his outstanding contributions in the field of chemistry, Government of Pakistan awarded him with Tamgha-e-Imtiaz and Pakistan Academy of Sciences with Gold Medal.

Prof. Dr. Darakhshan Jabeen Haleem

Dr Darakhshan Jabeen Haleem is Meritorious Professor (Neuroscience) at Dr Panjwani Center for Molecular Medicine & Drug Research, ICCBS, University of Karachi, Karachi. Formerly, she has served as Dean, Faculty of Science and Chairperson, Department of Biochemistry, University of Karachi. Actively engaged in teaching and research for the last 35 years, Prof Haleem has authored a number of research publications in high impact factor international journals of Neurochemistry, Neuropharmacology, Biochemistry and other life sciences. She has supervised 35 PhD and MPhil and 50 Master’s theses. She introduced and developed Biochemical Neuropharmacology, Biochemistry of Drug Action and Behavioral Pharmacology Sections in Department of Biochemistry, University of Karachi. She was a pioneer faculty member and first Chairperson of Department of Biochemistry, Federal Urdu University. She has written text books on various topics of neuroscience, viz., Neurochemistry of Drug Action, Neurochemistry, and Neuropharmacology and Behavior.

Prof. Darakhshan Haleem is organizer of International Study Group for Biochemical and Biophysical Research in Pakistan (ISBBP), life member of Pakistan Society of Biochemists, Pakistan Pharmacological Society, and International Brain Research Organization. She is Guest Editor & Reviewer of Neuroscience Journals published by Elsevier and Hindawi. Prof Haleem’s research has focused on the molecular and neural basis of Stress, Depression, Anorexia, Addiction, Memory and Search for Receptors and Signaling Molecules involved in the Potential Use of Psychostimulants for Enhancing Memory Function, and Treatment of Obesity and Narcolepsy. She has introduced an innovative research idea of developing psychostimulants as non-addictive...
cognitive enhancers. Her research has been funded by the Higher Education Commission, Pakistan Science Foundation, and University of Karachi.

Dr Darakhshan Haleem secured academic positions and distinctions in ISc, BSc and MSc. She was awarded Central Overseas Training Scholarship for PhD studies at British Postgraduate Medical Federation, Institute of Neurology, University of London on “Serotonergic functions in depression”. During her PhD she received Overseas Research Student (ORS) Award in London and the Young Scientist Award to attend 17th meeting of International Study Group for Tryptophan Research (ISTRY) held in Nagoya, Japan.

She was awarded DSc degree by The Open International University for Complementary Medicine, Colombo, Sri Lanka. Also, in recognition of her research contributions, she was awarded Gold Medal by the Pakistan Academy of Sciences, Nishan-e-Zafar and Nishan-e-Azmat Danish by University of Karachi, Ezaz-e-Fazeelat by the President of Pakistan, and Star Woman Award 1996 and Life Time Achievement Award by International Star Women Foundation. The Pakistan Council for Science and Technology (PCST) has ranked Dr Haleem as a Productive and one of the Top Scientists of Pakistan.

Dr. Abdul Rashid

Dr. Abdul Rashid is a distinguished Soil Scientist with extensive R&D and science management experience. He earned his PhD (Agronomy & Soil Science) from University of Hawaii, Honolulu, USA, after winning an East-West Center scholarship. He initiated his research career in 1973 in the pioneer research group on micronutrients at Nuclear Institute for Agriculture & Biology (NIAB), Faisalabad. In 1979 he joined Pakistan Agricultural Research Council (PARC), and spent most of his career at National Agricultural Research Center (NARC), Islamabad – as a researcher and a research leader, where he finally rose to the position of Chief Scientist & Director General. Subsequently, he served as Member (Bio-Sciences), Pakistan Atomic Energy Commission (PAEC).

Dr. Rashid’s problem-solving soil fertility and plant nutrition research, focusing predominantly on micronutrients and fertilizer use efficiency, identified and established deficiency of Boron, Zinc and Iron in many crops, and developed cost-effective fertilizer use technologies to manage the nutrient disorders. His farmer-friendly technologies, recommended by the agriculture departments and adapted by the farmers, are: (i) Boron fertilizer use in rice; (ii) Boron and Zinc fertilizer use in cotton; (iii) Zinc-enriched rice nursery; and (iv) 50% phosphate fertilizer saving band placement in wheat. Also, he has added substantially to the world literature on plant analysis interpretation criteria. His micronutrient research is recognized globally.

Dr. Rashid has authored/co-authored 280+ publications, including journal articles and reviews, encyclopedia & book chapters, the only textbook of Soil Science in Pakistan, and a Soil-Plant Analysis Lab Manual (in English, Russian & Arabic). He is Editorial Board Member of European Journal of Agronomy (Elsevier) and Communications in Soil Science & Plant Analysis (Taylor & Francis).

Dr. Rashid is a Past-President of Soil Science Society of Pakistan. He was invited as a Visiting Scientist to CSIRO Land & Water, Adelaide, Australia – as a Crawford Fund Fellow and to International Center for Research in the Dry Areas (ICARDA), Syria. Dr. Rashid has been invited to many major international conferences on crop nutrition and fertilizers, and has travelled widely. Also, he has organized many conferences and trainings.

Dr. Rashid’s innovative and problem solving research and effective writings have brought him many prestigious honors and recognitions, like IFIA (International Fertilizer Industry Association, Paris) Norman Borlaug Award, East West Center Distinguished Alumni Award, Government of Pakistan’s Dr. Norman Borlaug Award, PARC Silver Jubilee Award, and Fellowships of Indian Society of Society of Soil Science and Soil Science Society of Pakistan.

Currently, Dr. Abdul Rashid is Editor-in-Chief at the Pakistan Academy of Sciences.
Citation of the PAS Foreign Fellow Elected in 2013

The following eminent scientist was elected Foreign Fellow of the Pakistan Academy of Sciences during 2013:

Prof. Dr. Fatima Z. Basha

Prof. Dr. Fatima Z. Basha, Lead Scientist at Abbott Laboratories, N. Chicago, USA, is among the most prominent synthetic organic chemists of Pakistani origin. She got her MSc with first class first position in organic chemistry from University of Karachi working under the supervision of Prof. Dr. Salim-uz-Zaman Siddiqui. On the advice of Prof. Dr. Atta-ur-Rahman, Fatima Basha proceeded to USA for her PhD with Prof. Dr. Franck at Fordham University. After completing her PhD in organic synthesis in 1977, she joined Prof. Dr. Weinreb’s group at Fordham where she finished the first total synthesis of streptonigrin. Dr. Basha was hired by Prof. Dr. Hecht for post-doctoral research in one of the most premier academic institution of the world, the Massachusetts Institute of Technology (MIT), Boston, USA (1978-81). At MIT, Dr. Fatima Basha worked on the total synthesis of anticancer compounds such as bleomycin and verrucarin which earned her an international recognition.

In 1981, Dr. Fatima joined the Drug Discovery Research Area of Abbott Laboratories, Chicago as a research scientist and very soon rose to the rank of senior group leader. She proved her ability to lead in the field of drug discovery and development by using her outstanding skills in organic synthesis. She made notable contributions in several therapeutic areas such as cardiovascular, neuro-urology, antiinfective and immunoscience. In recognition of her scientific contributions in drug design and synthesis, she was elected in Abbott’s prestigious Volwiler Society during 1991.

As a scientist of international stature, Dr Fatima contributed immensely in the field of medicinal chemistry, synthetic chemistry and drug design. She has over 64 research papers in top international journals and 31 US and World patents to her credit. She has been invited in all major conferences of the world as plenary and invited speaker, including American Chemical Society National and Regional meetings and IUPAC conferences.

Throughout her stay in USA, Dr. Fatima remained engaged in helping Pakistani scientists and capacity building of young researchers. After the sudden demise of her only son, Mr. Umaer Basha, she decided to put her life long savings and her life to help young generation of Pakistan. She built the massive building of Umaer Basha Institute of Information Technology (UBIT) in University of Karachi, an exact replica of the MIT building, for over 2,000 students of information technology, computer science, and applications of ICT tools in production sector. She sent a large number of young Pakistani chemists to top laboratories of USA for further trainings, through Umaer Basha Foundation (UBF) USA. Along with this, she decided to help the H.E.J. Research Institute of Chemistry to establish world class synthetic chemistry, where she is currently engaged in training of bright young Pakistani researchers in the important field of organic synthesis.

In brief, the life and contributions of Prof. Fatima are par excellence and she is a human being of great attributes. Her contributions in the field of organic chemistry and her services to Pakistan are notable and praiseworthy. In recognition of her tremendous national services, in 2006 the President of Pakistan awarded Tamgha-e-Imtiaz to Prof. Dr. Fatima Basha.
Obituary

Prof. Dr. Shahzad Ahmad Mufti, *FPAS* (1942-2013)

Prof. Dr. Shahzad A. Mufti, Adviser (Biosciences), COMSATS Institute of Information Technology, Islamabad and former Chairman, Pakistan Science Foundation breathed his last in the early morning of Monday, December 30, 2013 after a brief illness in Islamabad.

The sad news spread like a wild fire in the entire country. The scientific community in general and zoologists in particular were shocked with the unexpected news.

Prof. Mufti was born on August 14, 1942 in Khanewal to a very well respected school teacher. He later shifted to Ichhra, Lahore and continued with his secondary and higher secondary school education. In 1959, he joined Government College, Lahore and obtained his B.Sc. degree in 1961 and M.Sc. degree in Zoology in 1963 from University of the Punjab. Because of his brilliant academic career, he was selected as Lecturer in Zoology in University of the Punjab, soon after his M.Sc. In 1969 he won the scholarship of Central Overseas Training Scheme of Government of Pakistan and proceeded to USA for his doctoral degree. He obtained his Ph.D. degree from Case Western Reserve University, Cleveland, Ohio, USA in 1970 in the field of Anatomy/Developmental Biology. Later, he rejoined his faculty position in the Department of Zoology of University of the Punjab, where he became Assistant Professor in 1970, Associate Professor in 1979 and Professor in 1987. During this period he also availed of postdoctoral positions in University of Michigan, USA in 1974 and then in 1978. He also served as Associate Professor of Bio-medical Sciences, Ohio University, USA during 1980-1984.

In 1990, Prof. Mufti decided to move to Islamabad, where he was appointed as Director General, Pakistan Museum of Natural History (PMNH). During his tenure of 11 years he had a pivotal role in development of PMNH and bringing it to an international level institution. Later on, he became Chairman, Pakistan Science Foundation. Because of his eminence in the field, Prof. Mufti was elected President of Zoological Society of Pakistan for the tenure 2001-2003, and Fellow of Pakistan Academy of Sciences in 2003. He also served as Treasurer, Pakistan Academy of Sciences during 2011-2012.

Prof. Mufti was a unique blend of an Artist and a Scientist which reflected in all facets of his life. He was a very popular teacher, known for his eloquence and sense of humor. His pioneering work in Teratology, besides his fascinating studies on regeneration of muscles from a finely chopped muscles, is part of Pakistani science history. His knowledge and love for paintings, Urdu poetry, classical Indian/Pakistani music and ghazals was evident from the time, no matter how little, one would spend in his ever refreshing company. He himself was a very good singer and would oblige his students on request and his colleagues and friends, even without request.

Prof. Mufti was a very caring husband and a father. He was in the habit of discussing every event of the day with his wife and family and hence would
enjoy his sleep at night without the routine mental stresses.

We have lost in him a very competent Developmental Biologist, a kind teacher, a thoughtful friend and a God fearing nice human being. May Allah rest his soul in peace and give fortitude to his students, friends, colleagues and family members to bear this irreparable loss.

Prof. Dr. Abdul Rauf Shakoori
Prof. Dr. Khalid Mahmood Khan
Fellows, Pakistan Academy of Sciences
Aims and Scope: Proceedings of the Pakistan Academy of Sciences is official journal of the Academy, published quarterly, in English. This open access journal publishes research papers in Engineering Sciences & Technology, Life Sciences, Medical Sciences, and Physical Sciences. State-of-the-art reviews (~20 pages, supported by recent references) summarizing R&D in a particular area of science, especially in the context of Pakistan, and suggesting further R&D are also considered. Manuscripts undergo double-blind review. Authors are not required to be Fellows or Members of the Pakistan Academy of Sciences or citizens of Pakistan.

Manuscript Format
Manuscript may contain Abstract, Keywords, INTRODUCTION, MATERIALS AND METHODS, RESULTS, DISCUSSION (or RESULTS AND DISCUSSION), CONCLUSIONS, ACKNOWLEDGEMENTS and REFERENCES and any other information that the author(s) may consider necessary. The Manuscript sections must be numbered, i.e., 1. INTRODUCTION, 2. MATERIALS AND METHODS, and so on.

Manuscripts, in Times New Roman, 1.5-spaced (but single-space the Tables), with line numbering and one-inch margins on all sides on A-4 size paper, should not exceed 20 pages including Tables and Figures. Number manuscript pages throughout. The text (in Font Size 11, except for the sections mentioned in Font Size 10) must be typed in a single column across the paper width. All Tables and Figures must be placed after the text, i.e., after REFERENCES section.

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