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PAK-CHINA ECONOMIC CORRIDOR

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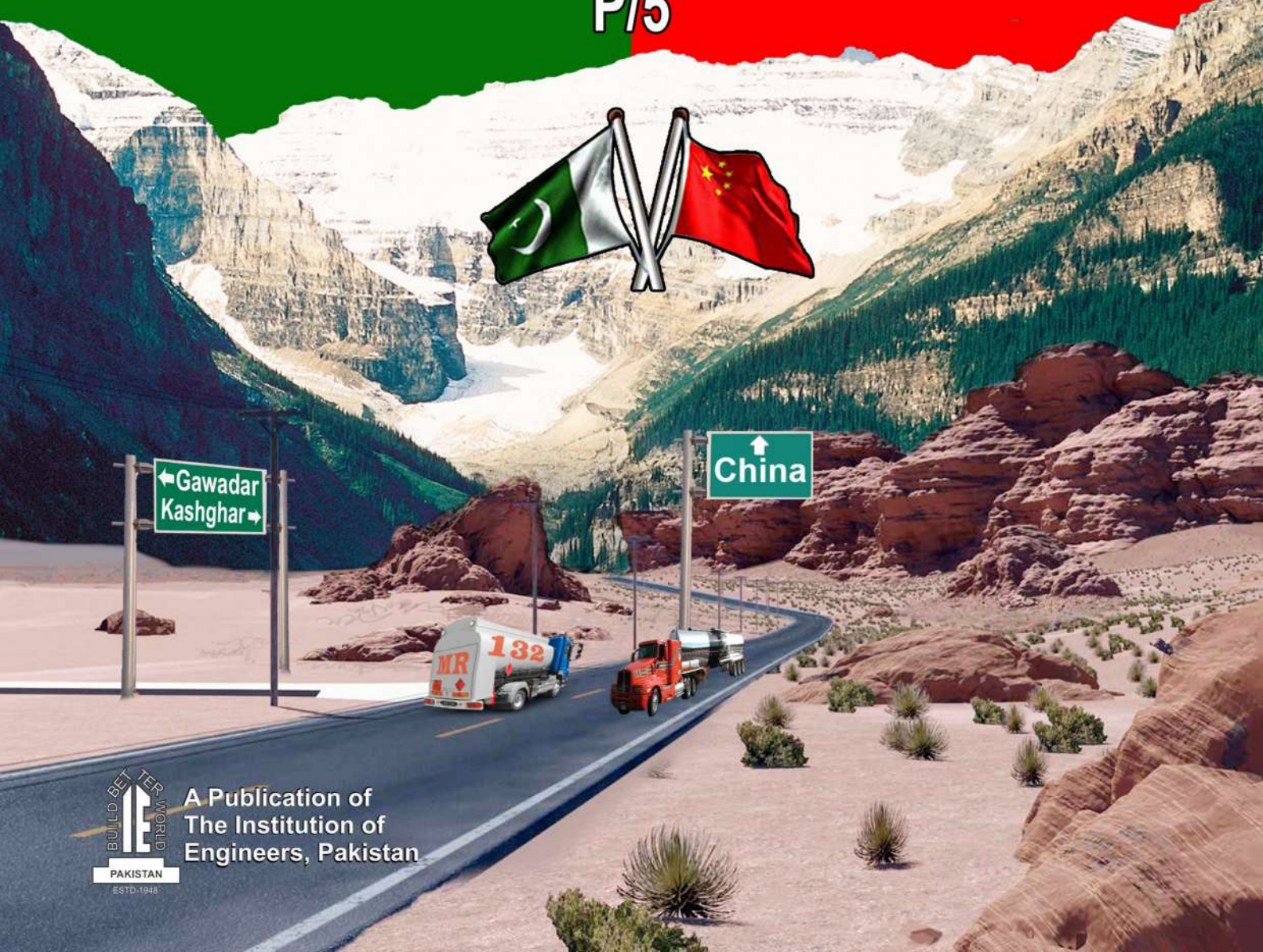

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"If Pakistan is to take its proper place among the progressive nations of the world, it will have to take up good deal of leeway in the realm of scientific and technical education which is so necessary for the proper development of the country and the utilization of its resources. The establishment of institution like the Institute of Engineers will greatly stimulate technical research and help in disseminating available information. The Institute of Engineers will not only benefit the engineers themselves by improving their technical knowledge but also bring lasting benefit to public services which they are called upon to perform.

I wish the Institute every success".

(Quaid-e-Azam's message to the first inaugural meeting of the Institute of Engineers on 20th June 1948)

Published By
The Institution of Engineers, Pakistan

Engr. Muhammad Ashraf
Director General

Business Offices
Raja Muhammad Rafique
Director Admin & Publications

IEP Headquarters Building,
Engineering Centre,
Main Boulevard, Gulberg-III,
Lahore, Pakistan
Ph: 042-35754043, 35750699

Fax: 042-35759449
e-Mail: iephqr@gmail.com

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Raja Muhammad Rafique,

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China-Pakistan Economic Corridor Facts in the Light of Ground Realities

Engr. Muhammad Ijaz Dar
mijazdar@gmail.com
mijazdar@hotmail.com

1. PROJECT AT A GLANCE:

As a professional engineer, I have concrete reason to believe that this is not a simple Road connection Project but in my opinion, it is long route passage, initially passing through the WESTERN part of Pakistan, covering both Baluchistan and KPK , to further connect Gawadar city with Khunjrab in KPK and then to Kashgar ,in China.

In the long run it will be extended up to Central Asian States including countries of South East Asia.

For that matter, in the very first instance it was imperative to improve the status of Gawadar city. The process to improve the status has already been initiated through development of Gawadar port and Gawadar International Airport.

Construction work at both the sites has commenced and it is expected that both may become operational, in the very near future.

Gawadar port is being developed with multiple infrastructure facilities equipped with latest and most modern equipment, presently available at all international ports, throughout the world, to handle all incoming and outgoing cargo.

2. MY PERCEPTION OF DEFINING ECONOMIC CORRIDOR, IS AS UNDER :

Being a professional engineer, I have absolutely different opinion about China-Pakistan Economic Corridor, as against, what the Political hierarchy particularly that in KPK had thought of it.

Politicians had thought that it will be Road Structure which will pass through their villages and in return they will earn dollars in cash.

I have seen discussions in the talk shows and special presentations on the TV Channels as well as read various articles in the print media. Let us first see what the two words corridor and economic mean. In simple words, corridor means a long passage and Economic stands for the prosperity which could be either good or bad. I therefore would define Economic Corridor, as a long route passage which will generate & not create prosperity for the people of those areas through which it will pass.

As a result of the developments which are likely to takes place, due to vast activities as are being envisaged, may become a reality , in the very near future .

Another factor which must be kept in mind is that beside industrial developments in the economic zones, the cargo carried through this passage will also generate money.

Because containers carrying cargo will pay toll tax in cash at pre-determined places.

This money in fact, will be, for the people of Pakistan as a whole but particularly for those living since generations, over there.

Job opportunities created, through multiple economic activities, in the Economic-Zones will improve the overall Economy of the whole area.

I am therefore of the firm opinion, that once the corridor become operational, it will not only influence the Political but also the Economic, Social and environmental culture of the whole area, through which this corridor will pass.

3. MY PERSONAL EXPERIENCE ABOUT THE CORRIDOR:

While looking on the map from where the corridor will pass, I can visualize and look back to the year 1987 when I was one of the participants of the First. Advanced course in public administration, at National Institute of Public Administration, at Quetta. I have almost travelled through the whole areas from Quetta to Mustang, Kalat, Khuzdar, Pasni, Punjgoor,

Turbat and right up to Gawadar, all these places are now going to become part of this Corridor.

How amazing it will be for me to see, containers loaded with cargo passing through these roads, where I along with my colleagues had travelled in a coaster van, for miles together during summer time. Not to speak of a human being, there was neither any animal nor any bird, we could see on the ground.

It was only near the coastal areas where we saw some birds flying in air.]

4. CORRIDOR, AS IT LOOKS TO ME:

As an engineer, having travelled all over the world and have also seen the Sydney Harbour when it was under construction.

There is no comparison between the two. Sydney harbuor was only confined to a small area having a classic engineering design. But my opinion about this economic passage is that:

It is going to be a big engineering project with multi-dimensional activities, involving economic, financial, Administrative, IT Experts, Engineers of all disciplines working together in this project.

And once it become operational it will, cover the entire Region, starting from KHASHGAR in China to Khunjrab and passing through the existing Shahrai-Resham connecting Peshawar to Kabul in Afghanistan, D.I. Khan in KPK.

Quetta, Chaman, Kalat, Turbat & up to Gawadar in Baluchistan. Gradually countries of Central Asian States will also become part of this corridor.

The project, in my opinion therefore, is not going to be completed in the next five years but it will take more time than the anticipated period because of the gravity of work and also with the increase of economic activities.

In view of the facts, narrated above, I am very optimistic that more countries in the region, would also wish to join this economic corridor after completion of the first phase. And in the long run, countries of South East Asia may also become part of this corridor.

5. PRIORITIES RELATED WITH THE PROJECT:

1. First and the foremost priority should be, to make Gawadar Port and Gawadar International Airport operational.
2. Connection of Khunjrab with Gawadar, through Road Net work.
3. Identify the areas where minerals are available.
4. Economic zones be established either near the mining areas or within their vicinity.

Following factors be kept in mind while selecting the sites of Economic Zones.

(i) Availability of water for drinking and arrangements for its disposal.

(ii) Locations of Industrial, Residential, Hospitals and health care centers, Commercial areas etc. in each zone.

(iii) Availability of Sufficient man power, i.e. Technical non-technical, skilled- un-skilled staff.

(iv) En route facilities, for cargo operators, staff involved in business, construction and other works etc.

As far as operation of Gawadar port and Gawadar International Airports, is concerned:

(i) Construction work on both the locations has already been started and is expected to be completed in the near future.

(ii) Construction of Road net work has already started in Baluchistan and to some extent in KPK as well.

6. INFRASTRUCTURE AND ESSENTIAL FACILITIES REQUIRED:

Corridor infrastructure facilities will include:

Road connections in and out, too and fro movement of traffic, Communication Network, establishment of Industrial Zones at selected places. But most important factor is, to have ample power generating capacity, sufficient enough to cater for the power requirements of plant and machinery to be installed at Gawadar city including its port and airport and the Industrial Zones. Total generating power should be enough to cope with the existing and future requirements of the industrial hubs, all over Pakistan, keeping in view its need for the next five to ten years.

For that purpose, first and the foremost priority should and is, to have trouble free Communication Network all along the route of the corridor, through Satellite or fiber optic cable, for quick and efficient communication system.

These facilities will create hundreds and thousands of job opportunities and healthy environments, not only for the poor & the neglected people but for the talented young persons who will also get benefitted through this Development.

As a result, Economic Conditions of both the provinces i.e. KPK and Baluchistan will flourish in particular and for the people of Pakistan, as a whole.

The corridor although consist of Western, Middle and Eastern Routes but preference has been given to the Western Route, most part of which is expected to be completed by the end of year, 2016.

Another breakthrough which this project will bring , is that:

It will enhance the Trade capabilities of all the countries in the region by manifold but most beneficiary will be Pakistan & its people, because all operation in & out shall be operated and handled from Pakistan.

Realizing this pivotal Role of Pakistan, China has come forward to take the lead.

Of course, the Chinese Government and its people shall also be benefitted because it will be the shortest and the cheapest Route, which will play a great role in boosting their Exports and ultimately their Economy, for which China was inspiring to become number one Economic Power in the world, since long.

This dream might become a reality if all things go well and the project starts working as per schedule. This will become a turning point in history, not for the Chinese but for Pakistan and its people, as well.

7. ROAD NETWORK:

Road network from khunjrab to Peshawar and Islamabad already exist through Mansehra and Abbottabad.

But the Network from Khunjrab to Mansehra, requires improvement which should be the top priority for making the corridor functional.

On the other hand construction work on the road network from Gawadar city towards Khunjrab has already been started. Detail of which are as under:

1. Road network on Gawadar-Turbat-Hoshab section stretching over 193 Km, has since been completed at a total cost of Rs. 19 billion.

2. Road network on the following sections is in progress and is likely to be completed by the end of Dec. 2016.

(i) Hoshab-Punjgoor-Nag-Basima-Surab section ,consisting of of 450 km and the estimated cost is Rs. 23 billion.

(ii) Surab-Quetta-Chamman Section consisting of 116 Km and the estimated cost is Rs. 9 billion

(iii) Khuzdar-shahdad kot Section comprises of 151 Km and the estimated cost is Rs. 8 billion.

After completion of the above sections, most parts of the western corridor i.e. from Gawadar to Quetta and Chaman,n entering into Afghanistan will become operational.

8. MISSING LINKS:

Following sections have been identified to be linked with the main corridor but these links may increase due to additional requirements, with the passage of time.

Therefore all the identified links will, ultimately get connected with the main corridor, to become its part.

The links are :

(i) Zob-Morkot section, 81 Km and the estimated cost is Rs.9 billion. The work on this section has already been started.

(ii) Qila Saif-ullah-Lorali-Jagam section, 128 Km & the estimated cost is Rs. 17 billion.

All formalities have been completed and the work is expected to be started soon.

(iii) Work on Mach-Kharan section is at preparatory stage and the estimated cost is Rs. 10 billion.

9. IMPROVEMENT OF ROADS:

Improvement of Road Network is always considered essential and is a continuous process which is carried out according to the demand and need but for the time being it has been decided that:

Quetta-Khuzdar high way, be made two way.

10. FUTURE LINKS TO CONNECT CENTRAL ASIAN STATES:

Following sections of Road Network will connect the corridor with the Central Asian states through:

(i) Basima-Khuzdar-Shahkot &

(ii) Bela-Awaran-Hoshab Sections

11. LINKING PESHAWAR WITH AFGHANISTAN:

Peshawar-Jalalabad high way is being constructed by FWO, financed by Government of Pakistan.

Jalalabad to Kabul section will jointly be built by both Afghanistan and Pakistan.

12. CONCLUDING REMARKS:

The Economic Corridor, as it appears, is not a network of roads but is a part of long term plan, consisting of Road Network, all sort of infrastructure, Industrial zones covering facilities of all fields of engineering related projects required for Industrial growth. Therefore, no one should expect that, this corridor will be completed in few years.

It is going to be a long term process which will extend its facilities to the neighboring countries who may wish to join this corridor, in future. Therefore, the plan may go beyond the anticipated period which has been estimated.

That is why it is now being said that plan will be implemented in phases. Reason being, such huge projects are always splitted and completed in phases.

Moreover, it is also imperative that all the Industrial zones must adjust their activities keeping in view the complete rapidly emerging technologies changing overnight, all over the world.

This no doubt will bring prosperity for all the people of Pakistan but for those, who are living in Baluchistan and KPK in particular, shall start getting the benefits immediately, if the project is completed according to the announced schedule. This will turn their fortunes because all of them will get benefitted, through its timely completion.

It is also pertinent to mention that not only Pakistan and Pakistani People shall accrue the benefits but the surroundings Countries in the region will also be benefitted through this corridor.

I must mention here, the role, China has played and the efforts she is making to complete the project, are much more than what Europeans or the Americans had ever thought of it.

There were predictions, that in the twenty first century, center of economic activities will shift from Europe towards Asia. Now time has come when this dream is going to become a reality, once the corridor is completed.

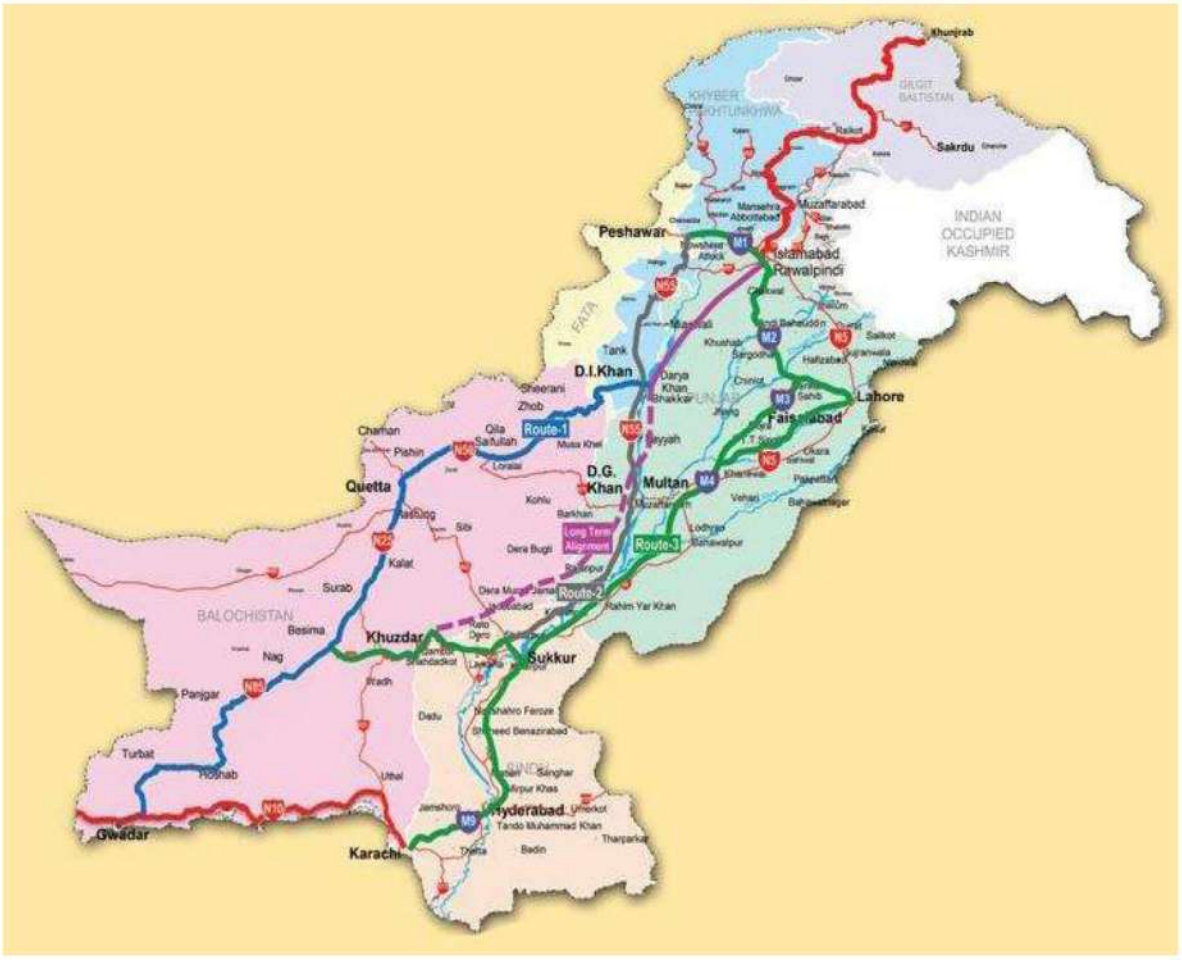
All credit and respect goes to the present Chinese Leadership and the Chinese people who are working hard day and night, to make this dream a reality.

We must thank the Chinese President and the Prime Minister for their endeavors and firm commitment and assurance for timely completion of the first phase of the project.

We should also not forget the role of Chinese Embassy in Pakistan which is very important and appreciable because they were the initiator and kept themselves in touch with the ground realities which made the Chinese Government to act in a positive way.

Role of Chinese Embassy and its Honorable Ambassador is therefore commendable.

Last, but not the least, the most beneficial country will be PAKISTAN, Pakistani people and the Pakistani Leadership, both Civilian and the Military ,for their commitment who stood like ROCK for early initiation and working hard for in time completion of the first phase of the project .The results are before us and people have seen on the TV Channels, Commander of the armed forces, driving with the Prime Minister, on completion of first section of the project, from Gwadar to Hoshab. We, therefore can inspire that at the end of the day things will start revolving around Pakistan and it will become



the center of gravity of this Economic Corridor.

ROAD MAP

Position of Construction of roads under the project is as under:

1. Gawadar-turbat-hoshab, m-8, 193 km at a total cost of rs. 19 billion has since been completed.
2. Hoshab – punjgoor-nag-basima-surab section, 450 km, estimated cost rs23 billion.
3. Khuzdar-shandad kot: 151 km ,estimated cost rs: 8 billion
4. Surab-quetta-chaman: 116 km estimated cost rs: 9 billion s# 2, 3 and 4 are under construction and likely to be completed by the end of 2016.
5. Qila saifullah, lorili-jagam, 128 km: estimated cost, rs 17.5 billion .all formalities completed, construction work to start soon.
6. Mach-kharan on preparatory stage, estimated cost rs. 10 billion.
7. Zhob-more kot 81 km estimated cost rs: 9billion work already started.
8. Quetta-khuzdar high-way to be made two-row
9. Basima-khuzdar-shandad kot
10. Bela-awaran-hoshab
    9 & 10 projects will connect, central asian states
11. Peshawar-jalabad highway under construction by FWO.
12. JALABAD-KABUL to be constructed jointly by govt. Of pakistan and afghanistan to connect south and central asian states from china to pakistan.
13. Karachi-lahore highway under construction.

POWER PROJECTS

1. 600 MW coal from Thar & under construction
2. 3480 MW from Coal in future. Gwadar international airport is under construction
3. Rajanpur : wind power : 250 x 4 = 1000 MW, with Denmark assistance.
4. Rahim Yar Khan:
   660 x 2 = 1320 MW Coal Power Plant with china Assistance.

Pakistan's Experience with Post-Earthquake Reconstruction and Rehabilitation

Engr. Muhammad Masood Rafi
rafi-m@neduet.edu.pk

Engr. Sarosh Hashmat Lodi
sarosh.lodi@neduet.edu.pk

Engr. Sohail Bashir
sohailbs@yahoo.com

Engr. Aziz Jamali
jamalidmg@gmail.com

ABSTRACT
Pakistan lies in a seismically active region of the world. Recent earthquakes caused damages in different parts of the country. This paper presents the details of post-earthquake rehabilitation and reconstruction strategies and activities which were carried out in two earthquake affected areas in Pakistan. These activities are essential to bring life to the normal. In both cases, owner driven reconstruction approach for private housing provided successful results in terms of safe and seismic resistant construction which was completed in time. This approach also provides opportunities for capacity building of large number of people which helps in increasing the resilience of communities against natural hazards. Complete rehabilitation may, however, take longer time as this involves participation of several agencies.

KEYWORDS: earthquake, rehabilitation, reconstruction, damage, cob material; confined masonry.

1. INTRODUCTION

Pakistan is blessed with four seasons, diverse topographical features and varied climate in different parts. These elements, in some cases, are also responsible for different natural hazards the Country faces from time to time. Further, similar to other developing countries, Pakistan experiences the problems related to varied population density, unplanned development in disaster prone areas, vulnerability of population segments and poverty. These factors have compounded with the lack of disaster preparedness and emergency planning to increase the risk of property and life loss across Pakistan. As a result, many natural hazards turned into disasters in the recent past and created unprecedented impacts on human settlements in different parts of the Country.

Human response to natural hazards has been a subject of intense investigation and study.

These hazards have proved the most difficult enemy of mankind as they are able to cause destruction on a large scale close to human settlements.

The events of natural disasters may be identified by excessive magnitude, frequency or duration (Arey and Bauman 1971, Bolt et al. 1975).

The study of human history indicates that the ability of natural hazards to cause destruction is partly due to lack of preparedness of human beings to mitigate the effects of these hazards. Different natural hazards include hurricanes, floods, tornados, typhoons, famine, fires, landslides and earthquakes. Of all these hazards, an earthquake is considered as the most disastrous natural hazard owing to its ability to cause devastation in terms of high number of human loss, and wide spread building and infrastructure failures and sufferings.

Pakistan lies in a seismically active region. The north and western sections of Pakistan (which are located along the boundary of the Indian plate, and the Iranian and Afghan micro-plates) have been the centre of earthquake activities.

(Fig. 1)
From Kalat (in the northern Makran range), Chaman Fault runs all along Pakistan's western frontier with Afghanistan; it passes by Quetta and enters Kabul in Afghanistan (DRIP 2014). An active fault also runs

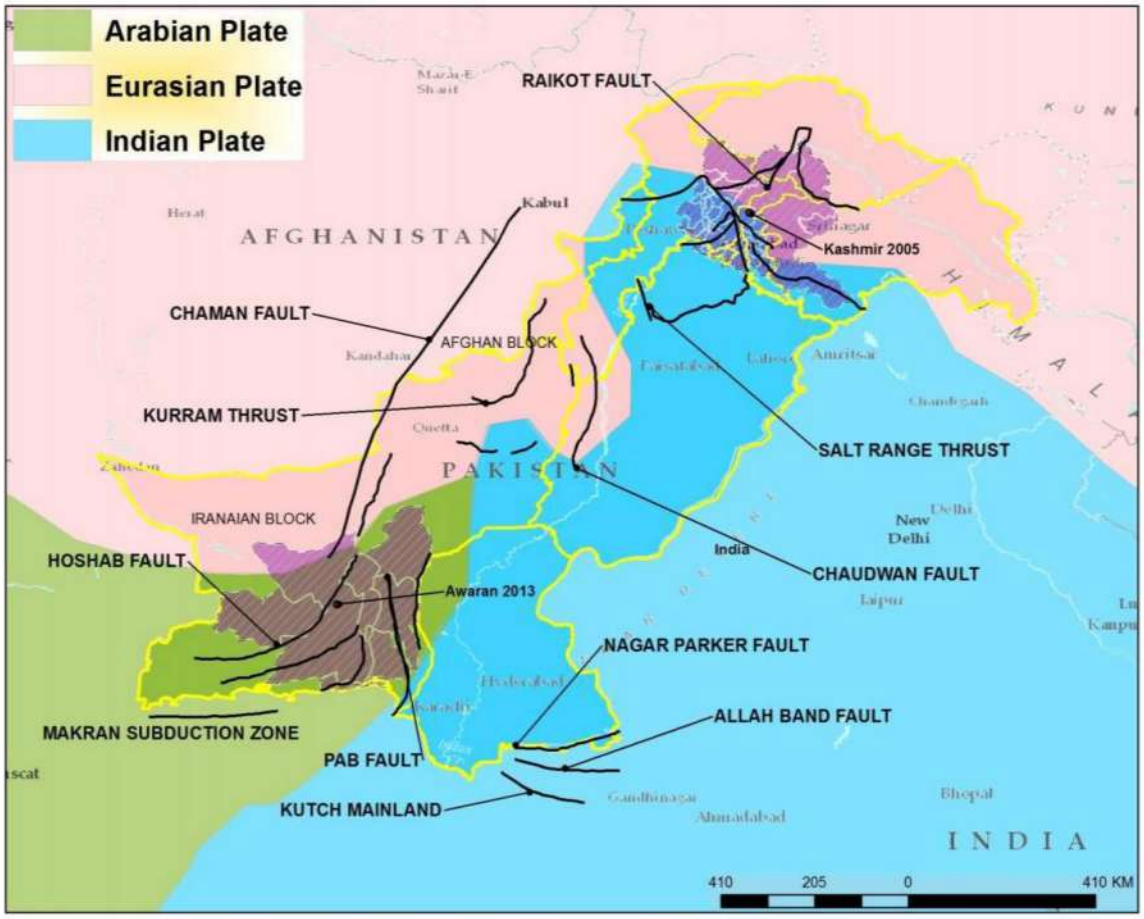


Fig. 1 Seismo-tectonic settings of Pakistan along the Makran coast where an active subduction zone exists off the coast (DRIP 2014). This is no surprise that the coast of Pakistan has been affected by tsunamis in the past.

The seismic threat for different parts of Pakistan has been demonstrated by a number of recent earthquakes. An earthquake, being a natural hazard, cannot be controlled; however, the risk associated with the building damages during an earthquake can be mitigated. Disaster preparedness and mitigation prevent a hazard from turning into disaster which can reduce the efforts for reconstruction and rehabilitation (R&R) of the affectees after an earthquake. The need of RR also indicates the level of resilience of a society; lesser the need higher the resilience and vice versa. This paper presents two case studies related to R&R in the aftermath of earthquakes in Pakistan. The lessons learnt from these experiences are based both on the available literature and the authors' personal observations due to their involvement with the R&R activities on the sites of both seismic events.

2. CASE STUDIES

2.1 2005 KASHMIR EARTHQUAKE

This earthquake occurred on 8 October 2005 in the northern parts of

Pakistan. The magnitude of the earthquake was recorded as 7.6 on Richter scale. The districts which were affected by this earthquake are highlighted in Fig. 1. Based on the destructions caused, this can be termed as the most devastating earthquake in the recent history of Pakistan. More than 73,000 people were killed and, at least 69,000 people were injured (ERRA 2006) due to the collapse of buildings during this earthquake. In addition, about 2.8 million people were made homeless owing to the damage of nearly 450,000 buildings (Rossetto and Peiris 2009).Table 1 summaries the damages in the affected districts.

Apart from houses, the earthquake also made significant damages to the buildings of educational centers. A total of 6298 centers were destroyed or damaged which comes out to be 67 percent of the total institutional facilities in these regions (ERRA 2006). The collapse of educational buildings caused deaths of nearly 18,000 students. Fig. 2 illustrates a distribution of damaged educational facilities. The total estimated cost of damages of these facilities came out to be US$ 54525 million (ADB/WB 2005). Heavy damages were also caused to infrastructure facilities such as water and sanitation, power supply infrastructure, roads and communication infrastructure.

Considering the scale of destruction and devastation,

Table 1. Statisticsof damages and reconstruction of houses inaffected districts (ERRA 2006)

District	Destroyed		Moderate Damage		Slight Damage		Reconstruction	
	Number	Percent	Number	Percent	Number	Percent	Planned	Completed
Muzaffarabad	121,995	89	12,499	9	2,891	2	131,932	123,062
Bagh	79,514	96	2,716	3	627	1	84,509	76,838
Poonch	39,190	83	7,209	15	1,084	2	39,326	36,689
Shangla	141,141	54	8,514	33	3,277	13	15,151	14,398
Mansehra	106,523	70	32,702	22	11,933	8	106,653	65,323
Kohistan	6,323	46	4,850	35	2,646	19	11,976	10,088
Abbottabad	19,704	31	17,982	28	22,585	35	21,073	19,673
Battagram	49,345	85	7,035	12	1,777	3	52,783	39,396
Total	436,735		93,507		46,820		463,403	415,467

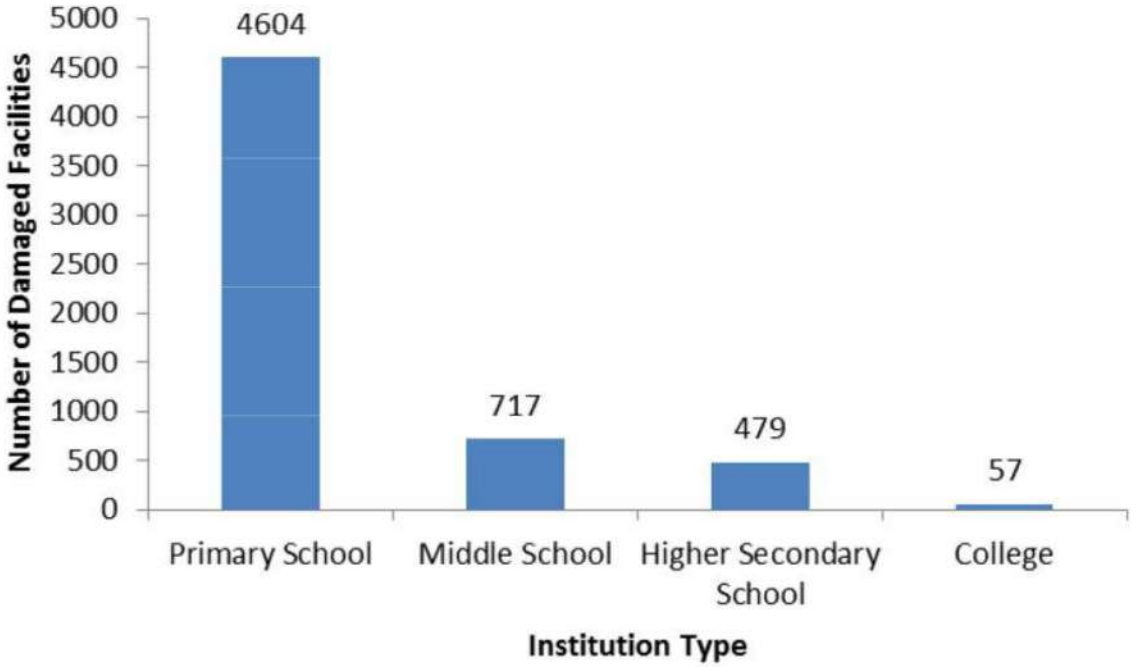
devastations, R&R was a paramount challenge. According to the initial estimates, housing reconstruction required 44 percent of the total reconstruction cost (ADB/WB 2005).

affected areas. The local governments of these areas were made responsible of micro level planning and implementation of R&R activities in coordination with ERRA.

Fig. 2 Damaged educational facilities in earthquake affected areas (ERRA 2006) the Kashmir earthquake was termed as Qa'yamat (Halvorson and Hamilton 2010) which is an Arabic phrase for the 'Day of Judgment'.

After mobilizing in the affected areas, relief agencies of Government of Pakistan, and national and international organizations started their efforts for establishing temporary shelters, caring for victims, rebuilding

The policy of owner driven construction with the slogan of 'build back better' was adopted by ERRA. The building design proposed in the earthquake affected areas was based on light-weight construction using



2.1.1 REHABILITATION AND RECONSTRUCTION ACTIVITIES

This earthquake happened at a time when there was little (if any) awareness about the consequences of earthquakes existed in Pakistani. As a result, the communities were completely unprepared and the capacity to deal with the aftermath of such tragedy did not exist. In view of the aforementioned scale of damaged structures and infrastructure, and resettlement of affectees(Halvorson and Hamilton, 2010).

Earthquake Reconstruction and Rehabilitation Authority (ERRA) was established by Government of Pakistan in March 2006; it was given the mandate of planning and coordination of R&R activities in the

wood and corrugated galvanized iron sheets. A number of international agencies and organizations also provided architectural styles and seismic resistant design for houses (Halvorson and Hamilton 2010). ERRA mobilised nearly 600 teams in the field to provide training and technical advice for seismic resistant construction to the people and to monitor progress of reconstruction

work. These teams provided training to 84,000 home owners (ERRA 2006). Financial grants were provided only to those affectees who followed safe construction guidelines issued by ERRA for the construction of houses. ERRA arranged for master plans to rebuild the affected towns scientifically according to these master plans. A summary of the planned and reconstructed houses until October 2008 is given in Table 1. It is noted in Table 1 that nearly 90 percent of the planned houses were completed.

The damaged educational facilities were reconstructed with the help of local governments, sponsors and donors. Since a significant number of people were made disabled by the earthquake (Rafi et al. 2010), the rehabilitation programme included such designs of hospitals which should provide better access for the disabled. The medical staff members were provided special trainings related to the type of injuries inflicted by the earthquake.

2.1.2 ISSUES AND CHALLENGES

Apart from private housing, the rehabilitation programme also included drinking water supply systems, sanitation systems, restoration of power sector, reconstruction of roads and bridges, and provision of modernized telecommunication infrastructure. Unfortunately, many of these were not completed on timedue to multiple reasons.For example, reconstruction of public buildings especially education and health facilities took much longer time and efforts than planned initially. TheERRA'sapproach of futuristic and grand building construction, both in quality and size, may be blamed for this delay which made it difficult to achieve the targets within available resources. Nevertheless, rehabilitation of water supply schemes succeeded next after housing owing to its close connection with livelihoods.

Halvorson and Hamilton (2010) identified that the issues related to housing reconstruction included higher cost of lightweight construction material such as wood and CGI sheets, and difficulty faced by people in accessing the information about specific construction methods or available construction material.

2.22013 AWARAN EARTHQUAKE

The Awaran, Balochistan earthquake occurred on 24 September 2013 (Fig. 1). According to United Sates Geological Survey, the magnitude of earthquake was 7.7 on the Richter scale whereas its focal depth was 20 km. The epicentre of earthquake was 66 km north-northeast of Awaran. The districts Awaran and Kech were badly damaged by this earthquake where significant life and property losses were reported. The most affected areas in these districts include tehsils Gashkor, Mashkai and Awaran of District Awaran and tehsil Dandar of District Kech. A summary of the damages and losses due to this earthquake is given in Table 2. In addition, 43 water supply schemes and 25 water channels were also damaged by the earthquake in the affected districts. Fig. 3 illustrates view of building damages in Awaran.

2.2.1 REHABILITATION AND RECONSTRUCTION ACTIVITIES

In the aftermath of this earthquake, the provincial government of Balochistan along with its line departments started a R&R rehabilitation programme for the victims. It was termed as

Table 2. Damage and losses due to Awaran earthquake (NDMA 2013)

Area	Casualties		Affected Villages	Damaged Houses		Damaged Schools	Damaged Health Facilities
	Death	Injury		Partial	Complete		
Mushkay	179	158	45	12961	6151	33	6
Mangoli			20	411	95	14	1
Awaran	174	255	90	20129	12422	53	13
Kech	46	186	83	10236	6844	47	1
Total	399	599	267	32638	14118	147	21

Fig. 3 Damaged buildings in Gajjar Housing Reconstruction in Awaran (HRA) Project.

A project director was appointed for HRA to execute and monitor the reconstruction activities. In view of the present bitter experience of damages and losses by the deficient construction, the Government of Baluchistan decided to promote seismic resistant construction to avoid similar incidents of damages and losses due to the future earthquakes.

The authors were engaged by the Government of Baluchistan to assist in the designing of earthquake resistant houses for the people in Awaran.

Similar to several other parts of Baluchistan, earthen materials such as adobe and cob were the predominant material types for private housing in the affected region. These materials offer several advantages such as low cost construction without modern technology and skilled manpower, and better thermal insulation. Although these buildings are considered weak in their resistance to earthquake forces worldwide research activities have indicated that their seismic resistance can be increased keeping the fabric of the buildings intact. Therefore, the design of a seismic resistant earthen building was carried out by the authors which was tested.

Fig. 4 Model of earthen construction with earthquake resistant features using a shaking table (fig.4). This type of testing is one of the highly reliable and most sophisticated methods for the evaluation of seismic performance of different structures. Based on the satisfactory performance of the model during the shaking table test, the design was implemented in the construction of houses in the affected areas.

HRA Project followed owner driven reconstruction approach whereby people were enabled to build their houses by themselves by providing them the necessary training and funds. The reconstruction activities started in July 2014. A number of model houses were constructed by HRA in different places throughout the affected areas to educate home owners (Fig. 5). Brochures and visuals were also used to disseminate the necessary information on the construction of safe houses. The authors presented lectures and workshops on safe housing construction. Close monitoring of construction activities was carried out by HRA with the help of field support staff members to ensure that the guidelines are followed during construction. As a result of these efforts, construction of 6000 houses was completed in December 2015 (18 months from the start of HRA project). In addition, Communication and

Fig. 5 Views of seismic resistant model houses in Awaran: (a) cob house; (b) CM house Works (C&W) Department of the Government of Balochistan started construction of 65 schools and 7 health facilities in different areas in January 2014 and was able to complete construction of 25 schools and 5 health units by December 2015.

In addition to earthen building, design of confined masonry (CM) houses comprising of one and two rooms was also carried out by the authors on the request of HRA. For the execution of this design, capacity building of masons was carried out in NED University by providing them on-site training of different construction activities. Fig. 5 illustrates CM model houses constructed by HRA in Awaran.

2.2.2 ISSUES AND CHALLENGES

The issues faced by the HRA project management were related to the demands of larger room sizes by the people due to cultural reasons compared to those proposed in the seismic resistant design of houses. Similarly, resistance from some sections of people was experienced towards theowner driven construction policy and the capacity building training sessions. Nevertheless, it was made clear by the project management that any deviation from the guidelines would result in stoppage of financial assistance. This proved to be the most effective deterrence to stop violations of the instructions of HRA project management.

As a result of courtesy mobilization efforts and masonry trainings, reconstruction of housing units surpassed the pace and quality of construction manifested by contractors/builders of education and health facilities. While in one year only 25 school buildings were constructed by C&W Department of the of Government of Balochistan using contractors, HRA was able to complete the construction of 5000 houses. Based on this experience, community construction model has been suggested to the Government of Balochistan for rebuilding damaged school buildings.

CONCLUSIONS

This paper presents an overview of rehabilitation and reconstruction experience in Pakistan from two recent earthquakes. Important conclusions drawn from the study are listed as under

1) Owner driven construction provides an effective model for private housingreconstruction in disaster stricken areas. It can be linked with monitoring, disbursement of funds, and training and capacity building of home owners. This approach ensures transparency in the disbursement and utilisation of funds and facilitates timely completion of work.

2) The engagement of higher educational institutions is beneficial in providing efficient seismic resistant design and capacity building of builders and craft persons. The required level of knowledge and skills can be transferred to both the home owners and the builders.

3) Delays in the reconstruction of public infrastructure facilities could be results due to coordination issues between different agencies. Community based reconstruction of these facilities can provide an alternative similar to the approach for private housing reconstruction.

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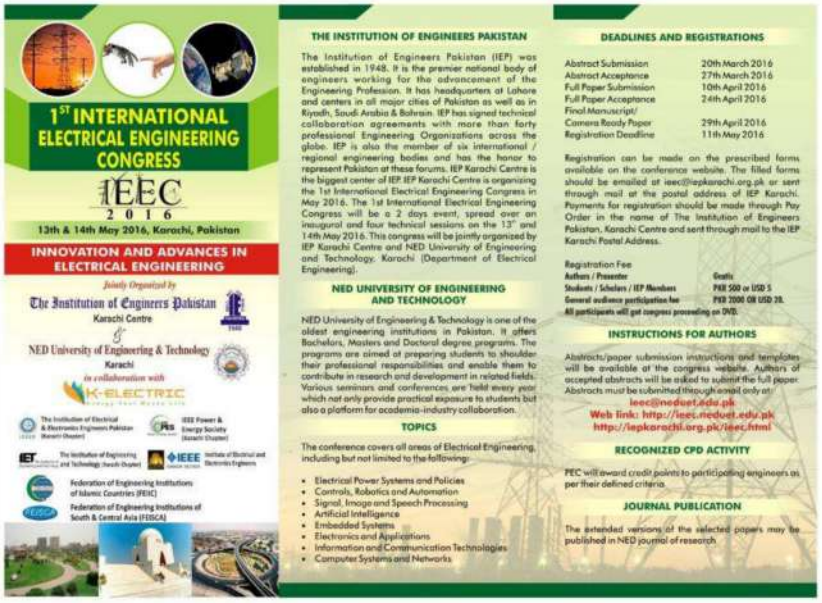

Experimental Study on Recycled Concrete Using Dismantled Road Aggregate And Baggase Ash

Engr. Salim Khoso
engr.salimkhoso@gmail.com

Engr. Abdul Aziz Ansari
dransari@quest.edu.pk

Engr. Jam Shahzaib Khan
jam_shahzaib@hotmail.com

Engr. Farhan Hussain Wagan
farhan_hussain_4u@yahoo.com

ABSTRACT
In this experimental work demolished road aggregate and sugarcane bagasse ash (SCBA) which are large disposal landfill materials are used as replacement materials in concrete. SCBA obtained from sugar mills is used. Total of 246 specimen of cubes and cylinders were cast with 100% coarse aggregate replaced with dismantled road aggregate whereas the cement replacement was in the percentages 5%, 10%, 15%, 20% and 25% by weight for curing period of 7, 14, 28 and 56 days. Compressive and tensile strength tests were done and the result showed that the concrete specimens made by replacing 10% of cement by SCBA at curing period of 7 and 14 days gave an unpredictable increase in test results that compete and almost reach the strength of traditional concrete. A decrease in strength was also observed at curing periods of 21 and 28 days. However, again an abrupt increase was also observed after curing period of 56 days. The workability of cement concrete was decreased with the addition of sugarcane bagasse ash.

KEYWORDS
Recycling, Baggase Ash, Dismantled aggregate, Bitumen, Concrete

1. INTRODUCTION

Recycling and waste reduction both are extremely important elements in the framework of waste management, because they help to preserve mainly the natural resources and reduce demand for valuable landfill space (Ling *et al* ., 2013). However, in major cities of Pakistan there is a rush in demolition and construction waste quantities posing an adverse effect on the environment
Utilization of such waste as recycled aggregate in concrete can be useful both for environmental protection and economical aspects in the construction industry. Global demand for construction aggregates exceeds 26.8 Billion tons per year. In Pakistan there is a significant increase in the use of natural aggregates due to infrastructure and construction development. The use of recycled aggregate in construction industry started since the end of Second World War by using a demolished concrete pavement as recycled aggregate.

On the other hand Sugarcane bagasse, is the fibrous residue that is obtained after crushing and extracting sugarcane juice, and is main industrial waste product from sugar mills in Pakistan. Nowadays, it is very common to reuse sugarcane bagasse as a biomass fuel in boilers for vapor and power generation in sugar factories. In spite of being a material of hard degradation and that presents few nutrients, the ash is also used on the farms as a fertilizer in the sugarcane harvests. Depending on the incinerating conditions, the resulting sugarcane bagasse ash (SCBA) might have high levels of Si O and Al O , enabling its utilization as a supplementary pozzolanic material in concrete. Utilization of SCBA as a pozzolanic material to substitute ordinary Portland cement partially not only helps in reducing methane gas emissions from dumping of the organic waste and reduce the cement production, which is well-known for consuming high energy and CO emission, but can also play a vital role to improve the compressive strength of cement-based materials (Sirirat *et al*., 2010).

The work presented in this paper expresses the possibility to substitute virgin coarse aggregate with recycled concrete aggregate in

structural concre te. To achieve this objective demolished road wearing coarse was collected from National highway (N - 5) near Gambat city and number of cubes and cylinders were prepared using 100% virgin aggregate and 100% recycled aggregate obtained from dismantling road wearing coarse.

Tests were conducted for compressive and tensile strength of concrete. The results revealed that the road aggregate can be converted into useful recycled aggregate and could also be used in concrete for many structural applications around the world. Standard procedures were adapted to determine various concrete properties. A significant increase in the properties of cement concrete with the addition of SCBA was seen as compared to virgin aggregate concrete.

2. MATERIALS AND EXPERIMENTAL PROGRAM

2.1 MATERIALS

2.1.1 DISMANTLED ROAD AGGREGATE

Dismantled road aggregate was obtained from national highway Near Gambat city in Sindh. This Material was obtained by milling or full depth removal of wearing course from a section of National Highway (N-5) that was under maintenance project. Large pieces of dismantled road were brought to the laboratory and were broken into required size by hammering. Sieves of sizes 1", ¾" and ½" were used to get required size.

2.1.2 SUGARCANE BAGASSE ASH

Pakistan produces millions of tons of Sugarcane bagasse Ash each year from sugar mills. The SCBA used in this experimental work was collected from Ranipur sugar mill located around 80 kilometers far from the college on Ranipur – Kumb road in district Khairpur Sindh, Pakistan. The ash collected was the byproduct of sugarcane juice extraction of the session 2013-14. The collected ash was sieved due to present of straws of sugarcane and was made fine.

2.2 METHODOLOGY

The experimental work was conducted in the structural engineering laboratory of Civil engineering department at Quaid-e-Awam University College, of Engineering, Science & Technology, Larkana, Sindh, Pakistan. Total of 246 concrete specimens including cubes and cylinders were cast as shown in Figure 1. Dimensions of specimens were 150mm x150mm for cubes and cylinder specimen of 150mm diameter and height equal to 300mm. Aggregate ratio of 1:2:4 was used in preparing specimens by maintaining water cement ratio of 0.5 percent for all batches. After preparation of cube and cylinder samples, they were kept for curing period of 7, 14, 21, 28 and 56 days. The experimental work was done in two phases.

Figure 1: Casting of concrete specimens that are later put in curing tub.

Phase 1

In the first phase cubes and cylinders were cast without any cement replacement or supplementary material with 100% virgin coarse aggregate. The cube and cylinder specimens were cast with 1:2:4 aggregate ratio and 0.5 percent water cement ratio.

Phase 2

In the second phase cube and cylinder specimens were cast with 100% dismantled road aggregate as coarse aggregate. However, cement was replaced with sugarcane bagasse ash in the ranges of 5, 10, 15, 20 and 25 percent by weight.

2.3 TESTING PROCEDURE

Total specimens cast i.e. cubes and cylinders after completing the curing period of 7, 14, 21, 28 and 56 days were tested for both compressive and tensile strength. Compressive strength of all the cubes and cylinders is evaluated using Tecnotest universal load testing machine. Concrete specimens made by virgin as well as dismantled road aggregate were tested and the difference between two crushed samples can be seen in Figure 2.

Figure 2: Split cylinder specimens made by dismantled road aggregate and virgin aggregate.

3. TEST RESULTS AND DISCUSSIONS

The results of the experimental work conducted in which different type of concrete samples cast are shown in Tables 1, 2 and 3. Initially reference concrete specimens

of traditional concrete were cast for comparison of results. The study showed that cement concrete made by recyling coarse aggregate 100% with dismantled road aggregate and replacing cement by 10% of sugarcane bagasse ash reveled postive result that almost compete with the strength of conventional cement concrete. However some values showed that the concrete made with recycled aggregate and with sugarcane bagasse ash crossed the strength of refernce concrete samples. It was observed that the peak values were obtained at curing periods of 7 and 14 days. However, the strength gradually decreased at curing periods of 21 and 28 days and abrubtly increased at curing period of 56 days again. Figure 4,5 and 6 shows the cube compressive strength results at different curing periods and cement replaced partially with different ratios.

3.1 COMPRESSIVE STRENGTH TEST OF CUBES

Table 1 and Figure 3 shows the compressive strength test results of concrete made by replacing cement with different percentage of sugarcane bagasse ash. The results show that there is increase in compressive strength for cubes at 10% replacement of cement by SCBA for curing period of 7 and 14 days only and gave approximately same value as that of plain concrete.

3.2 COMPRESSIVE STRENGTH TEST OF CYLINDERS

The results given in Table 2 and Figure 4 show the compressive strength test results of cylinder specimens made by replacing cement with different percentage of sugarcane bagasse ash with 100% replacement of coarse aggregate with dismantled road aggregate. The results obtained show that there is increase in compressive strength for cylinders at 10% cement replacement at curing period of 7 and 14 days that almost crossed the strength of plain concrete.

Table 1: Compressive strength Test results of cube specimens

S. No	Concrete sample	Compressive Strength (psi)				
		7 days	14 days	21 days	28 days	56 days
1	Plain Concrete (o% R.A + 0% B.A)	3276	3946	4000	4241	4425
2	Recycled Concrete (100% R.A)	2281	2334	2253	2192	3629
3	Recycled Concrete (100% R.A + 5% B.A)	2975	3254	2453	2256	3331
4	Recycled Concrete (100% R.A + 10% B.A)	3186	3852	2687	2456	3587
5	Recycled Concrete (100% R.A + 15% B.A)	3021	3107	2546	2345	2957
6	Recycled Concrete (100% R.A + 20% B.A)	1661	1801	1432	1360	1647
7	Recycled Concrete (100% R.A + 25% B.A)	1857	1972.6	1647	1588	1597

R.A = Recycled Aggregate B.A = Bagasse Ash

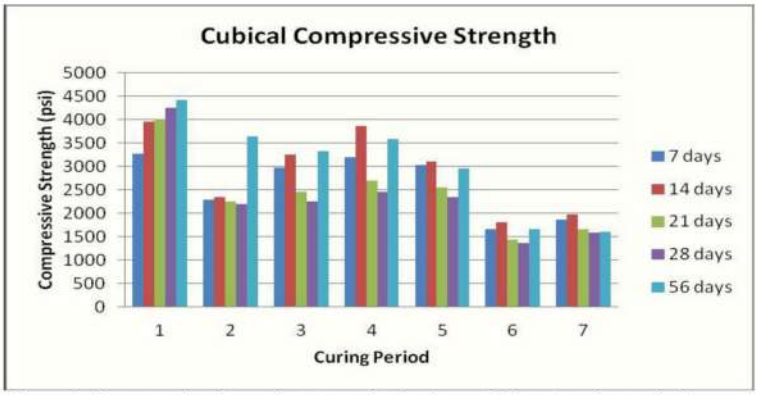

Figure 3: Compressive Strength test result of cubes at different curing periods

Table 2: Compressive strength Test results of cylinder specimens

S. No	Concrete sample	Compressive Strength (psi)				
		7 days	14 days	21 days	28 days	56 days
1	Plain Concrete (o% R.A + 0% B.A)	2016	2132.5	2211	2504	**2886**
2	Recycled Concrete (100% R.A)	1275	1578	1518	1434	**1792**
3	Recycled Concrete (100% R.A + 5% B.A)	1225	2034	1425	1383	**2032**
4	Recycled Concrete (100% R.A + 10% B.A)	**2260**	**2392**	**2115**	**2043**	**2488**
5	Recycled Concrete (100% R.A + 15% B.A)	1086	2168	1496	1529	**1958**
6	Recycled Concrete (100% R.A + 20% B.A)	1000	1405	1196	1110	**1556**
7	Recycled Concrete (100% R.A + 25% B.A)	1626	1405	1216	1115	**1263**

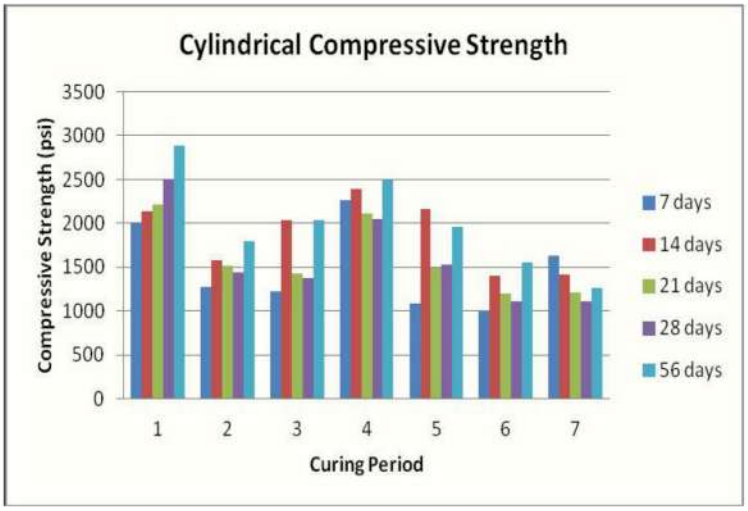

Figure 4: Compressive Strength test result of cylinders at different curing periods

Table 3: Tensile strength test results of cylinder specimens

S. No	Concrete sample	Compressive Strength (psi)				
		7 days	14 days	21 days	28 days	56 days
1	Plain Concrete (o% R.A + 0% B.A)	164.2	219	233	251	**273**
2	Recycled Concrete (100% R.A)	102	138	118	95	**101**
3	Recycled Concrete (100% R.A + 5% B.A)	104	109	86	83	**117**
4	Recycled Concrete (100% R.A + 10% B.A)	**168**	**210**	**134**	**129**	**188**
5	Recycled Concrete (100% R.A + 15% B.A)	117	122	113	111	**140**
6	Recycled Concrete (100% R.A + 20% B.A)	82	101	71	70	**102**
7	Recycled Concrete (100% R.A + 25% B.A)	76	88	81	86	**96**

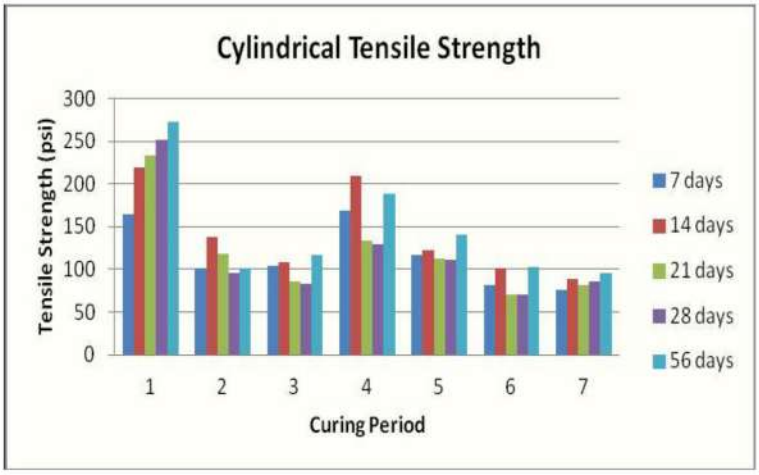

Figure 5: Tensile Strength test result of cylinders at different curing periods

3.3 TENSILE STRENGTH TEST OF CYLINDERS

The results in Table 3 and Figure 5 show the tensile strength test values of cylinder specimens made by replacing cement with different percentage of sugarcane bagasse ash and 100% replacement of coarse aggregate with dismantled road aggregate. Peak values of tensile strength have been obtained at 10% cement replacement by sugarcane bagasse ash at curing period of 7 and 14 days.

4. SUGGESTIONS

Results presented above are based on the experimental evaluation of 246 concrete specimens consisting both cubes and cylinders made by recycled aggregate and sugarcane bagasse ash. The study has revealed positive and acceptable results at 7 and 21 days curing. To get more positive results and the reason behind the sudden increase of strength after 56 days curing may be investigated by using aggregate of different sources.

Therefore , further analysis of recycled aggregates from various sources and experimental assessment of strength of more cubes and other models will not only give better perceptive but may also lead to better results. A supplementary material may also be used in order to get more accurate and higher values of compressive and tensile strength. This experimental work has been carried out by using sugarcane bagasse ash, however study can be carried out by using different pozzolanic materials in concrete made by recycled road aggregate.

5. CONCLUSIONS

The experimental study by using recycled aggregate and sugarcane bagasse ash revealed that,

1. The peak values were obtained when cement was replaced by 10% partially with sugarcane bagasse ash and coarse aggregate used was 100% recycled.

2. Increase in compressive strength value was obtained at curing periods of 7 and 21 days. The results almost reach the strength of plain concrete.

3. With increase of curing period that is 21 and 28 days the compressive strength was decreased. However, it was abruptly increased again at curing period of 56 days. This increase in strength again after 56 days can be because the bitumen stuck with the coarse aggregate became completely deactivated and the strength started to increase again.

4. Same results were also observed in tensile strength where the highest value was obtained at 10% cement replaced by SCBA after curing period of 7 and 14 days.

ACKNOLEDGMENTS

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Engineering Design Process

Calculating Quantity of Steel Bar Placed In Mesh Form in a Circular Slab or Dome

Engr. Karam Chand Gupta
kcgupta2007@gmail.com

ABSTRACT
When steel reinforcement is placed in mesh form in circular concrete slab at base or domes at top in case of over head service reservoir or any other structure, it is difficult to estimate/measure the total quantity of steel that would be needed or placed.

For the purpose of calculating the total length of the steel bars, at present, the practice is – the length of each bar is measured and then added up. This is tiresome and time consuming process.

I have derived a mathematics formula with the help of which we can calculate in one line the quantity of total steel that will be needed.
This will not only make it easy and time saving but also avoids any error in making entries and calculations.

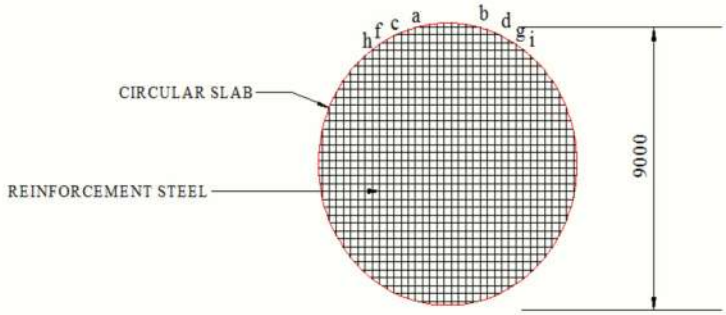
KEYWORDS
Steel, Estimation, Mesh, Slab, Spacing.

1. INTRODUCTION

It very easy to calculate steel quantity in rectangular or square concrete slab of a building. We multiply number of bars in one direction by length of one bar. But in case of circular slab at base or circular dome at top of a structure like Over Head Service Reservoir, it is difficult to estimate/measure the total quantity of steel that would be needed or placed.

For the purpose of calculating the total length of the steel bars, at present, the practice is – the length of each bar is measured and then added up. For example in Fig.1 the total length of steel bars is taken as equal to ab + cd + ef + gh and so on. This is tiresome and time consuming process. Error can also occur in long calculations. I have derived a formula with the help of which we can calculate in one line the quantity of total steel that will be needed or used in mesh of circular slab dome.

Figure 1: Steel Mesh



2. FORMULA

$L = \pi D^2/2s$

Where L = Total length of steel bar in m
D = Diameter of the circular slab/mesh in M
S = Spacing of steel on both directions in M

3. DERIVATION OF FORMULA

Suppose there is a circular slab having steel in mesh form within diameter D. Diameter of mesh is approximately equal to the diameter of the slab. But we will take in calculation the diameter of the mesh only. Spacing of the steel in both direction is 's'. Steel bars have divided the whole area of slab in to many squares with side 's'.

Total Area of Circular mesh

$= \pi D^2/4$

Area of one square with side "s" = s^2

Number of squares in the circular mesh = Area of circular mesh/Area of one square

$= (\pi D^2/4)/ s^2$

Total length of steel bar in one square = 4s

As each side 's' is shared by two squares, the length of steel bar in each square will be

= 4 s / 2 = 2s

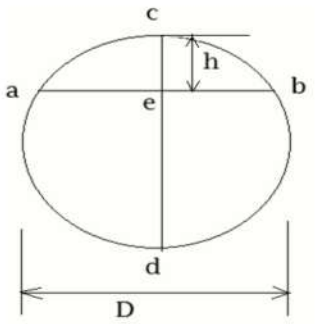


Figure 2

Therefore total length of the steel in circular slab

= Number of squares x 2 s

$= (\pi D^2/4\ s^2)$ x 2s

$= \pi D^2/2s$

4. PRACTICAL ASPECTS

5.

To check up the correctness of the formula either the length of each bar will be measured in the drawing or the length of each bar will be calculated geometrically with the formula and then add up so as to know the total steel and the result can be compared with the one calculate with the formula.

$$2\sqrt{h(D-h)}$$

(Where h is distance of steel bar from edge of mesh)

Suppose steel is provided at spacing 250 mm centre to centre in mesh having diameter 9 m. The lengths of steel bars in both directions will be as under:-

Table 1: Length Calculations

Length of steel bars going from top to bottom of the mesh.
And
Length of steel bars going from left to right of the mesh.

2.11
3.60
4.58
5.33
5.95
6.48
6.92
7.31
7.64
7.93
8.18
8.39
8.57
8.71
8.83
8.91
8.97
9.00
9.00
8.97
8.91
8.83
8.71
8.57
8.39
8.18
7.93
7.64
7.31
6.92
6.48
5.95
5.33
4.58
3.60
2.11

Total 254.83m
Total steel bar in mesh and

Total 254.83 m
=509.66 m

Total length of steel bar with the formula

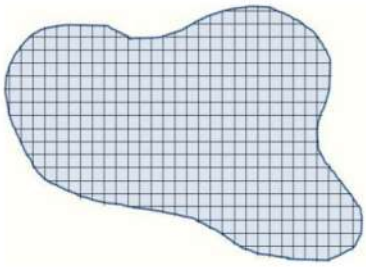
$= \pi D^2/2s$

$= \pi 9^2/2$ x 1.25

= 508.94 m

which is approximately equal to the length actually calculated above. Thus exact quantity of steel can be worked out and neither waste will be there nor short quantity of steel has been arranged.

Figure 3: Bed Slab of Lake



In case where spacing of steel bars is not same in both directions, then length of steel bar

$L = \pi D^2 (S_1 + S_2) / 4S_1 S_2$

Where S_1 is spacing of steel in one direction and S_2 in other direction.

In case of a spherical dome where spacing in both directions is same, then length of steel bar

$L = 4 \pi r h / s$

Where r is radius of dome

h is height of dome
s is spacing of steel in both direction

In case where the spacing of steel bar in both directions in the dome is not same, then length of steel bar

$L = 2 \pi r h (S_1 + S_2) / 4S_1 S_2$

Where S_1 is spacing of steel in one direction and S_2 in other direction.

For an irregular shaped figure just as bed slab of a lake, the length of steel will be

$$L = \frac{A}{s/2}$$

Where A is area of bed slab of lake which can be calculated with the planimeter of the drawing and 's' is spacing of the steel in both direction.

6. CONCLUSION

With the help of this formula we can calculate the exact quantity of steel to be provided in mesh form in circular slab or dome in one line. If this formula is adopted, a field engineer will be able to do the calculations in very easy

way and chances of error are very less. It will also save the lengthy paper work while estimating the steel for circular slab or dome.

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News Digest

IEP to Develop Partnership with Local Universities

Institution of Engineers Pakistan, Rawalpindi-Islamabad Chapter (IEP-RIC), will develop its partnership with local universities for enhancing professional development of young and newly graduated engineers.

It will also seek the support of the higher education insinuations to enhance its membership for collective benefit. Through the mutual collaboration, the two sides will hold lectures and seminars on professional matters in order to equip the engineers with new developments, enabling them to play their useful role in the country's socio-economic.

Similar collaboration will also be developed with Engineering Council Pakistan for community's welfare and professional development; it was decided at the Administrative and Finance Committee's meeting of IEP-RIC held here. It was presided over by its chairman Hafiz M. Ehsan Qazi.

While taking stock of the institutional work, it was noted that there was gradual increase of IEP-RIC memberships. The committee unanimously approved its budget and accounts of the recent months.

Programmes' In-charge Engr. Arjumund Shaikh welcomed participation and role of Young Engineers Forum (YEF) in achieving the desired goals. He briefed them about the institution's objectives, aiming at promoting Engineering Education, Knowledge disseminating and skills transfer.

The proposed plan of IEP linkage with various Institutions, Industry, NGOs (National and International) was also discussed in the meeting and it was decided that they will work vigorously to have better career of the young engineers.

Engr. Dr. Attaullah Shah stressed that 'YEF' needed to come forward and play its effective role in promoting and accelerating IEP-RIC activities. Engr. Gr. Cap. (r) Najamuddin called for conducting short courses in the relevant disciplines for the benefit of young engineers.

Engr. Osaf Malik underlined the importance of continuing Professional Development (CPD) Programme for professional grooming of young engineers. Such activities at the level of IEP should be a regular feature, he added.

Bio-Crude Oil from Microalgal Biomass to Produce Environmentally Friendly Higher Value Fuels and Chemical Compounds

Engr. Mehmood Ali

Engr. Ian A. Watson

Engr. Jaime Toney

Engr. Muhammad Saleem

ABSTRACT

The importance of microalgae as the third generation biofuel feedstock has been realized in recent years due to its potentially high oil yield (20 times higher than that from land crops). It is an alternative to fossil fuels and will reduce CO_2 emissions helping to tackle global warming. Autotrophic microalgae species such as *Chlorella vulgaris* can be cultivated in municipal wastewater on 350,000 acres of marginal lands in Pakistan with favorable climatic conditions; making this land useable to produce biofuels without competing with arable land. The wastewaters are rich in nutrients and these can be consumed for algal growth, improving the wastewater quality. The treated wastewater can be used for irrigational and industrial purposes, conserving the fresh water demand, while the algal biomass can be used as a feedstock to produce bio-energy. The potential of using *Chlorella vulgaris* wet biomass as a feedstock for hydrothermal liquefaction (HTL) was investigated Processing was done in a sealed batch reactor at two temperatures, 200 and 350°C in liquefaction water conditions at two holding times, 30 min and 60 min for each temperature. The highest bio-crude oil yields obtained were 0.064±0.007 and 0.273±0.015 (g/g of biomass) on a dry basis, measured at both reaction times, respectively, at a maximum temperature of 350°C The energy efficiency of the process at both experimental conditions were found to be 8.23% and 40.22% respectively. The measured nutrients in the aqueous phase were total nitrogen and total phosphorous of 4.58 mg/L and 333.07 mg/L for 30min reaction, while 2.28 mg/L and 795.80 mg/L were measured for 60 min treatment at the same temperature. The bio-oil had long chain fatty acids (C14-C18) which can be readily used in boilers and heavy engines and can be thermally upgraded to obtain gasoline, diesel and jet fuels.

KEYWORDS

Biofuels, microalgae, hydrothermal liquefaction, nutrients, energy recovery, Chlorella vulgaris

*Corresponding author: mehmood@neduet.edu.pk

1. INTRODUCTION

Due to the depletion of fossil fuel reserves and to comply with environmental degradation issues (Ali and Sheikh 2012) related to climate change and global warming (Xu *et al.* 2011), the importance of microalgae as a third generation biofuel feedstock has been realized. It has high oil productivity yield, up to 20 times the oil per area than vegetable seed crops, and they do not displace land for food crops. Microalgae are unicellular microscopic plants, heterotrophic or autotrophic photosynthesizing organisms (Bi and He 2013), with advantages over traditional feedstock in that many species are able to grow in salt (saline/coastal water) or wastewater (domestic/municipal /industrial wastewater) streams (Chen *et al.* 2013) and they are compatible for production of biofuels and co-products within bio-refineries. Ahmad *et al.* (2012) utilized the nutrients available in wastewater to grow microalgae as a feedstock for biodiesel production. Eutrophication of water bodies due to the discharge of wastewater rich in nutrients causes degradation of marine and aquatic ecosystems. Mixed algal species were investigated to uptake nutrients from wastewater, showing promising results. It was found that the maximum uptake of nitrate was

97% and phosphate was 93%. The potential of microalgae cultivation on uncultivated 350,000 acres of land with wastewater can make biofuel production commercially viable in Pakistan. Pakistan has suitable climatic conditions such as sunlight intensity (which is between 5.1-6.2 kWhr/square meter/day) which compares favorably for the requirements of microalgal growth via photosynthesis, which is 4.52 kWhr/square meter/day for its optimum growth conditions (Ali 2014). Furthermore, carbon dioxide emissions can be sequestrated to enhance microalgal growth and to meet the international commitments for global warning and climate change.

The fatty acid profile of microalgae lipids are similar to soybean vegetable oil and found to be a good candidate for biofuels production. The major challenges faced by the biofuel production facilities is the extraction of oil from wet microalgal paste with an economically viable method (Biller and Ross 2011). This issue can be addressed with thermochemical hydrothermal liquefaction treatment that can be applied to extract bio-oil and gaseous products directly from the wet algal paste with a high moisture content, a main advantage of this process is that it does not require feedstock drying. The process is important from the energy point of view as the energy consumption required by hydrothermal liquefaction (HTL) is very low compared to other processes (Shuping *et al.* 2010). The reaction involves obtaining low molecular weight liquid fuels from high molecular weight organic compounds, present in the biomass, at elevated temperatures and pressures, with or without a catalyst at different treatment times (Brown *et al* 2010).

The resulting bio-crude oil with heating values varies between 30-40MJ/kg can be used as a burning fuel in boilers or upgraded and refined into higher value fuel products (Illinois 2014). Hydrothermal liquefaction can be conducted at subcritical and supercritical water conditions, however, it has been that the extraction of bio-crude oil from algae at supercritical conditions is less effective and its quality is poorer than that extracted at subcritical water conditions (Toor *et al.* 2013). As the reaction temperature increases the unstable fatty acids undergo various reactions to form a wide range of useful chemicals. The major chemical obtained in the bio-crude oil is glycerol, derived from the rapid hydrolysis of less stable fatty acids. Increased amounts of alkanes were detected in bio-crude oil samples above the reaction temperature of 310°C and further increase in temperature decomposed the alkanes into gaseous products such as: carbon dioxide, carbon monoxide and methane. The bio-crude oil and the gaseous products from liquefaction capture as much as 90% energy content of the microalgal feedstock. An additional benefit of hydrothermal liquefaction routes is the potential to recycle process water which can be fed back into the alga l cultivation system because it is rich in essential nutrients such as nitrogen, phosphorous and potassium required for microalgal growth (Biller *et al* 2012). It is interesting to note that the rigid wall of microalgae might play an important role in protecting the protein present during hydrothermal liquefaction. This results in the highly nutritional solid residue, rich in nitrogen and minerals but low in carbon, can be utilised as an animal feed (Toor *et al.* 2013), fertilizer or bio-char (Biller *et al.* 2012). The extracted lipids (fats) fatty acids profile is an indicator of the physical and chemical properties of the microalgae derived biofuel (Ali and Watson 2015). The bio-crude oil from microalgae showed a fatty acids profile mainly constituents (44.9% GC-MS peak area) long chain fatty acids (C14-C18), which can be easily converted into hydrocarbon fuels (Du *et al* 2012).

This research investigation provides information about using microalgae biomass under different hydrothermal conditions to extract bio-crude oil as a source of alternative fuels. The hydrothermal liquefaction reactions were conducted at two different temperatures (200 and 350°C) with two treatment holding times 30min and 60min to investigate its bio-crude oil yields and its compositional fatty acids properties to convert it into hydrocarbon fuels. The aqueous phase and the solid phase after the reaction were also analyzed in terms of recovery of valuable products. The energy recovery of the process was calculated to look for its energy viability at the two holding times at 350°C.

2. MATERIALS AND METHODS

Chlorella vulgaris was procured from a commercial source (Wholefoods, UK) with a bio-chemical composition of protein 57.20%, carbohydrates 11.20% and lipids 8.70%. All the experiments were conducted at a room temperature of 24 ± 1°C and at a relative humidity of 50%, measured with a humidity temperature meter (Model: 1365, RS Components, UK). The experimental work was conducted at the School of Engineering, University of Glasgow, Glasgow, UK.

i. MOISTURE CONTENT MEASUREMENT OF BIOMASS AND ALGAL SLURRY

The initial moisture content (on % dry basis) of dried powdered microalgae biomass and prepared algal slurry for HTL experiments were measured by weighing the initial and the final weight of 1g samples after heating at 110°C for 1hr in an oven (Model: KWS-1525R-F2U, Cook Works Signature, UK) and weighing with analytical scales (Model: AS120, Ohaus Corp., USA).

ii. HYDROTHERMAL LIQUEFACTION PROTOCOL

Hydrothermal liquefaction was carried out in an unstirred batch reactor (25mL, Parr, USA) and charged with 1g of powdered microalgae sample and 9 mL of distilled water (Biller and Ross 2011) at a pressure ~ 200bar in water. An algal slurry was prepared by mixing vigorously. Then the algal slurry was

sealed in the reactor chamber and introduced into a muffle furnace (Model: 1294, Pyro- Therm Furnace Manufacturers, UK), until the desired treatment temperature was reached. The furnace heating rate was measured as 15°C/min. Following the liquefaction reaction, the reactor was taken out from the furnace and allowed to cool down at room temperature for 3hrs. Then the reactor vessel was opened and the reaction mixture was transferred into a 50mL centrifuge tube (Eppendorf, UK). The reactor was rinsed with dichloromethane (DCM) to clean its surfaces because most of the oil was stuck to the reactor walls. Then it was washed with distilled water and cleaned. Both DCM and distilled water (1:1) each with a volume 16.66 mL, were added to the reaction mixture. The centrifuge tube was shaken vigorously for 30s by hand and then centrifuged with a lab centrifuge (Model: 5810 Effendorf, UK) for 3min at 3000rpm (1811G). The lower layer with bio-crude oil with DCM was pipetted out and the DCM was evaporated at its boiling point, 40°C in a Techne sample concentrator (Model: DB-3, Bibby Scientific Ltd, UK) for 1 hr and then the bio-crude oil weight was determined. The bio-crude oil yield (g/ g dry microalgae biomass) was measured (on % dry basis) with the following equation:

Bio-crude oil yield = Mass of bio-crude oil with the container – Mass of an empty container

(EQ.1)

Where the mass of the bio-oil recovered and mass of the empty container were measured in grams. The upper aqueous layer and the residue solids were collected separately for further analysis. The residue solid recovered was dried in an incubator (Model: PIN-120, Carbolite Ltd., UK) for 3 hrs and then the difference between the weights of the solid biomass before and after drying operation gave its % dry weight.

iii. BIO-OIL GC-MS COMPOSITIONAL ANALYSIS

The GC-MS analysis of the extracted bio-crude oil was conducted at the School of Geographical and Earth Sciences, University of Glasgow, UK . The GC-MS analyser (QP 2010 Plus, Shimadzu, Japan) was used to identify compounds at different treatment temperatures with two treatment times.

iv. HIGHER HEATING VALUE (HHV) OF BIO-OIL

The higher heating value of the extracted bio-crude oil at 350°C for 30min and 60min samples were measured with an oxygen bomb calorimeter (Model 1341, Parr, USA) according to ASTM D2015, as per previous research work (Ali and Watson 2014).

v. DETERMINATION OF TOTAL NITROGEN AND TOTAL PHOSPHORUS IN A REACTION WATER

The aqueous phase after reaction was collected and centrifuged again for 3 min at 3000 rpm to remove any solid matter present in it for the determination of total nitrogen (TN) and total phosphorus TP). The total nitrogen (TN) and total phosphorus (TP) detection was conducted at the Civil and Environmental Engineering Laboratory, University of Strathclyde, Glasgow, UK with an Ion chromatography system (Metrohm 850/858, Cheshire, UK) as per the protocol (De Borba *et al.* 2014).

vi. ELEMENTAL ANALYSIS AND HIGHER HEATING VALUE (HHV) OF BIO-CHAR

The elemental compositional analysis was conducted with an analytical elemental analyser (CE-440, Exeter Limited, UK) at the School of Chemistry, University of Glasgow, UK. The % content of carbon, hydrogen and nitrogen was used to calculate the HHV (MJ/kg) of the bio-char obtained at different experimental conditions with the help of the equation (Friedl *et al.2005:*

HHV= 3.55 C^2 – *232 C -2230 H + 51.2 (C x H) + 131 N + 20600* **(Eq. 2)**

vii. ENERGY RECOVERY OF THE PROCESS

The energy balance of the hydrothermal liquefaction process was calculated at two treatment times with maximum bio-crude oil yield at 350° C for comparisons with the following equation (Biller and Ross 2011):

Energy recovery (%) = (HHV of bio-crude x mass of bio-crude / HHV of feed x mass of feed) x 100%

Where the HHV values of bio-crude and feed are in MJ/kg and the mass of bio-crude oil and feed are in grams.

3. RESULTS AND DISCUSSIONS

i. BIO-CRUDE OIL YIELDS AND ITS HIGHER HEATING VALUES

The moisture content of the dried microalgae powder was found to be 8.528 ± 0.552 (mean ± standard deviation, n=3), while the algal slurry moisture content was 90.196%. The reaction products are depicted in **Figure 1** , the recovered bio-char, bio-crude oil with DCM solvent and the light yellow aqueous phase can be compared to the original algal slurry, dark green colour.

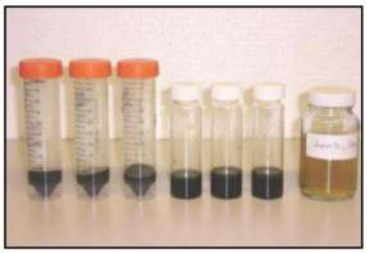

Figure 1: showing (from left to right) the bio-char (3 samples), bio-crude oil (3 samples) and the aqueous reaction phase (extreme right).

Table 1 was found that the highest yields were 0.064 ± 0.007 and 0.273 ± 0.015 g/g biomass at 350°C with both treatment times, 30 and 60 mins respectively. In contrast to the lipid yields of 0.014 ± 0.001 and 0.037 ± 0.002 g/g biomass at 200°C at 30 and 60 respectively. The extracted bio-crude oil had a high viscosity and was like tar. The retention time is also an important factor in bio-crude oil yield, which allows complete reaction

with higher bio-crude oil yields. According to previous research (Biller *et al* 2012), the bio-crude yield was low at 350°C (35.8% by weight) as compared to 330°C reaction temperature (46.6% by weight), here forced cooling of the reactor was achieved via compressed air blowing at approximately 20°C /min. But in the present case, the reactor was allowed to cool down to room temperature in 3hrs. The improved yield with treatment time is due to more time for the reaction mixture to interact, converting the organic matter into more bio-crude. Similarly, the increase in temperature results in higher pressure, which improves the solvent density and solubility of the target biomass, allowing the solvent to diffuse (following Fick's Law) more efficiently into the biomass molecular structure, thus enhancing the extent of biomass decomposition and fragmentation (Chan et *al.* 2015). The higher heating values (HHV) of the extracted bio-crude oil were found to be 26.40 MJ/kg and 30.24 MJ/kg at 350°C for retention times 30 min and 60 min respectively. The HHV obtained at 350 oC for 60min holding time was found similar with previous literature (Shuping *et al.* 2010).

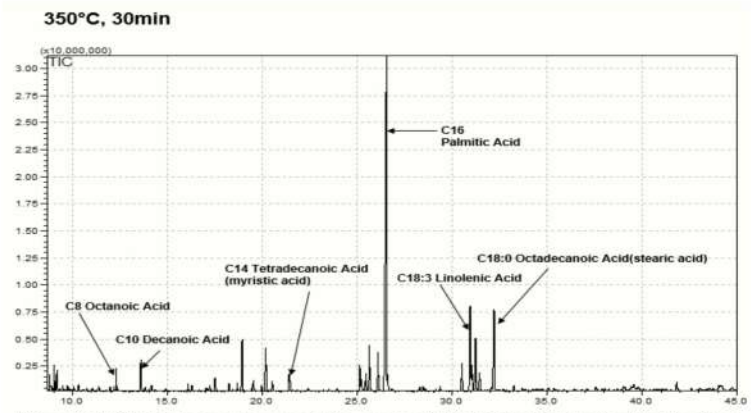

Figure 2: GC-MS chromatogram of bio-crude oil at 350°C with 30min retention time

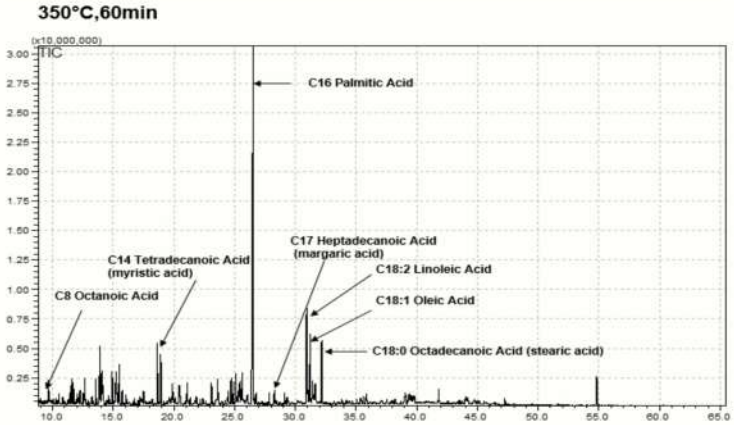

Figure 3: GC-MS chromatogram of bio-crude oil at 350°C with 60min retention time

Table 1: Bio-crude oil yield with respect to HTL

Time Min	Temperature (°C)	Cio-Crude oil Yield (g/g)	Bio –char Yield (g/g)
30	200	0.014±0.010	0.751±0.015
	350	0.064±0.007	0.559±0.062
60	200	0.030±0.002	0.724±0.035
	350	0.273±0.015	0.130±0.002

ii. GC-MS ANALYSIS

Figures 2 and **Figure 3** show the comparison of GC-MS chromatographs of the bio-crude oil extracted with hydrothermal liquefaction processing at 350°C with 30min and 60min holding times. The results showed the presence of octanoic acid, decanoic acid, tetradecanoic acid (myristic acid), palmitic acid, linolenic acid and octadecanoic acid (stearic acid) in both samples. The composition of the bio-crude includes fatty acids (C14 C18) which can be readily converted into hydrocarbon fuels (Du *et al.* 2012).

iii. RESULTS OF TOTAL NITROGEN AND TOTAL PHOSPHORUS

Table 2, shows the total nitrogen and total phosphorus results at both holding times (30min and 60min) with two temperature conditions. The presence of nitrogen and phosphorus compounds might be in the form of K, NH^{4+}, acetate, PO_4^{3-} and it looks promising that nutrients can be recycled for microalgae growth, lack of nutrients is one of the main economic constraints for microalgal biofuel production. All algae strains that are able to grow in recycled process water show heavy dilution of the water phase is necessary to avoid the effects of growth inhibitors such as phenol, fatty acids and nickel (Biller et al. 2012.

Table 2: HTL aqueous phase analysis results.

Time min	Temperature (°C)	TN (mg/L	TP (mg/L)
30	200	3.68	431.21
	350	4.58	333.07
60	200	4.58	362.44

iv. BIO-CHAR ANALYSIS

Chlorella vulgaris feedstock compositional analysis was 48.19% carbon, 6.88% hydrogen and 9.42% nitrogen, its higher heating value was calculated as 20.53 MJ/kg. The bio-char elemental composition and the HHV results are presented in **Table**

3. The results showed decreases in the carbon and hydrogen content with respect to increasing treatment temperature at both holding times due to the recovery of bio-crude oil from the biomass. The amount of carbon and hydrogen reduces with increasing temperatures in HTL processing and the results are in accordance with the literature (Toor *et al.* 2013). This results in a decrease in the HHV values with corresponding increase in temperature (Toor *et al.* 2013).

Table 3: Bio-char elemental composition and its calculated HHV values

Time (min)	Temperature (°C)	Elemental composition (%)			HHV (MJ/kg)
		C	H	N	
30	200	46.2	5.94	9.53	19.512
	350	42.5	4.06	9.83	18.221
60	200	45.95	5.79	9.62	18.841
	350	42.32	3.35	8.40	17.825

v. ENERGY BALANCE

The energy balance of the HTL processing at 350°C for both treatment times was calculated with Equation 3 and compared. The equation takes into account the amount of bio-crude oil and the feedstock with their respective HHV values and the results were 8.23% and 40.22% respectively. The results show a higher energy ratio with 60min treatment at 350 o C as compared to the 30min treatment at the same temperature.

4. CONCLUSIONS

This work indicates that the bio-crude oil yield was higher with 60min treatment as compared to 30min. The extracted bio-crude oil has free f atty acids that are desir able for production of hydrocarbon fuels with further bio-refining. The Bio-crude oil HHV as 30.248 MJ/kg, showing a 28.5% lower value as compared to petroleum crude oil HHV value 42MJ/kg. The total nitrogen and total phosphorus showed promising results for recycling the aqueous phase for cultivating microalgae. The residue bio-char from HTL processing can be used to produce biogas by anaerobic digestion, with HHV values comparable to the bio-char from wood (25MJ/kg). It can also be used as a soil conditioner or a building material with low thermal conductivity properties. Microalgal biomass can be converted into bio-crude oil for multiple fuel production such as: jet fuels, biodiesel, bioethanol, and hydrogen gas.

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Constructed Wetlands For Sustainable Wastewater Treatment

Engr. Atif Mustafa
atifm@neduet.edu.pk

ABSTRACT

Conventional wastewater treatment systems entail heavy investment and high operating costs. The contemporary wastewater treatment systems in most of the developing countries which were built through funding by international agencies fail to treat wastewater satisfactorily. Reasons for poor treatment include lack of local expertise, high maintenance costs and poor governance. When paralleled to conventional treatment systems, constructed wetlands are low cost, easily operated and maintained, and sustainable treatment systems. They have a strong potential for application in developing countries Constructed wetlands are accepted as a reliable low-cost and low energy wastewater treatment technology. They represent an appropriate solution for treatment of many wastewater types. Pilot scale constructed wetlands were commissioned at NED University to check their treatment efficacy.

Domestic and industrial wastewaters were treated separately under local environmental conditions. A free water surface wetland was used to treat domestic wastewater while a vertical flow wetland was used for industrial wastewater treatment. The studied constructed wetlands successfully removed the monitored pollutants from domestic and industrial wastewaters. The results confirm that constructed wetlands can successfully be used for wastewater treatment under local environmental conditions. Application of these systems on full scale can play an important role in managing the city's wastewater.

KEYWORDS

Constructed wetlands; Low-cost; Sustainable; Treatment; Wastewater

1. INTRODUCTION

Universally, most of the developing countries are situated in those parts of the globe that are or will experience water shortages in the proximate future. The current water sources of water supply are polluted because untreated domestic and industrial wastewaters are discharged into waters bodies resulting in diminishing water quality. This practice not only contaminates the sources of drinking water but also negatively impacts irrigation, fish production or recreation (Kivaisi, 2001). Water pollution is one of the main perils to public health in developing countries. Therefore, two measures that are wastewater treatment and wastewater reuse can play a vital role in combatting water scarcity. In the context of developing countries it is important that designers should select low cost and low maintenance technologies for wastewater treatment.

The mega city of Karachi has three wastewater treatment plants to treat sewage. A summary of these wastewater treatment plants is presented in table 1. Treatment Plant-I located at Haroonabad, SITE and Treatment Plant-II located at Mehmoodabad comprise of preliminary , primary and secondary treatment levels. The secondary treatment level is based on attached growth biological treatment system of trickling filter. While the Treatment Plant-III located at Mauripur is based on waste stabilization pond system. Around 472 million gallons per day (MGD) of wastewater is produced by the city. The above three sewage treatment plants have a treatment capacity of 151.5 MGD (KWSB), i.e. they have a capacity to treat only 32 percent of the total wastewater produced. But poor maintenance, weak institutional

capacity, economic constraints, poor governance and shortage of human resources have resulted in malfunctioning of these treatment plants. The treatment plants are now treating merely 12 percent of the total wastewater generated. This is not only the case for Karachi but the same applies to urban wastewater management in cities of developing countries.

and integration with landscape. The main objectives of this study are to:

1. To evaluate the performance of constructed wetland to treat domestic and industrial wastewaters;

2. To assess the application of constructed wetland for wastewater treatment in Karachi.

slotted openings. Immediately after plantation the FWSW was submerged with tap water so that the plants could establish themselves. After an establishment period of 6 weeks, the FWSW was fed with domestic wastewater for acclimatization. The plant growth was monitored during this period and found to be good. Pre-treated wastewater is collected in

Table1: Summary of Sewage Treatment Plants Located in Karachi (KWSB, 2015)

S.No	Plant Number	Location	Treatment Capacity (MGD)	Current Treatment (MGD)
1	Treatment Plant-I	Haroonabad, Site	51	20
2	Treatment Plant-II	Mehmoodabad	46.5	0
3	Treatment Plant-III	Mauripur	54	35
		Total	**151.5**	**55**
MGD: million gallons per day; SITE: Sindh Industrial and Trading Estate				

Constructed wetlands are considered to be a sustainable treatment alternative and have been successful in treating various kind of wastewater including domestic sewage. They are simple to construct, operate and have very low energy requirement.

The basic categories of constructed wetland systems are: free water surface (FWS) wetlands, horizontal subsurface flow (HSSF) wetlands and vertical flow (VF) wetlands (Kadlec and Wallace, 2009). Wastewater that has undergone primary treatment can further be treated in these low energy treatment systems.

The city of Kolkata, India has East Kolkata Wetland (EKW) that is a distinctive example of a wetland ecosystem. It provides a wide array of benefits including protection of environment and recovery of resources.

The wastewater generated by this city is diverted to the EKW through a network of drainage canals. The wetland system treats 145 MGD of raw sewage and storm water (Bunting beds and estuaries of Malir and Lyari rivers of Karachi can be utilized for developing wetland treatment systems. These systems have the potential to provide multiple benefits of wastewater treatment, biodiversity enhancement

2. MATERIALS AND METHODS

2.1 EXPERIMENTAL SETUP

Two experimental setups were developed at NED university campus. The first setup was developed for treatment of domestic wastewater (FWS wetland) while the second one was for industrial wastewater treatment (VF wetland). Details of the two setups are detailed in the following subsections.

2.1.1 DOMESTIC WASTEWATER TREATMENT SYSTEM

A pilot-scale free water surface wetland (FWSW) was commissioned at NED University of Engineering and Technology (Figure 1). The system is designed as a plug flow reactor for a flow of 1 m^3/d. It consists of a rectangular cell that has a length to width ratio (L:W) as 4:1. The rectangular cell was constructed with cement concrete blocks. Its base was made impermeable using concrete based floor. The cell was filled with sweet earth and fertilizer was applied during plantation of Phragmites karka. Soil tubes were used to collect young plant saplings of Phragmites karka from a natural wetland. Vegetation density was 4 plants per m^2.The constructed wetland inlet and outlet comprise of PVC pipes. For making the system hydraulically efficient the inlet and outlet pipes were fabricated with

a storage tank. Wastewater enters the treatment system through the wetland inlet pipe (regulated by a valve) and travels via gravity towards the wetland outlet pipe.

2.1.2 INDUSTRIAL WASTEWATER TREATMENT SYSTEM

The experimental set up consisted of two vertical flow constructed wetlands (VFCW) with different plants and media packed in ready-made pots made up of concrete (Figure 2). These pots have a diameter of 0.3 m and height of 0.45 m. A 10 cm bottom layer of gravel was capped with 24 cm layer of sand to facilitate plant growth. To collect samples, a valve made up of PVC material was fitted at the bottom of the VFCW.

The VFCW were planted with two plant species; Phragmites karka (VFCW 1) and Typha angustifolia (VFCW 2). Soil tubes were used to collect young plant saplings of Phragmites karka and Typha angustifolia from a natural wetland. Five collected saplings were planted in each VFCW. Immediately after plantation the VFCW were submerged with tap water so that the plants could establish themselves.

After an establishment period of thirty days, the two VFCW were fed with refinery wastewater for

acclimatization. The plant growth was monitored during this period and found to be good. Wastewater from a local refinery was collected in PVC vessels and transported to NED University for experimentation. The refinery wastewater was added manually. Hydraulic loading rate of 85 mm/d was maintained. The VFCW were operated on a pulse load system.

2.2 SAMPLING METHODS

DOMESTIC WASTEWATER

For wastewater analysis, grab samples were collected from the inlet and outlet of the FWSW after every two weeks from September 2010 to April 2011. Wastewater samples were tested for various physical, chemical and biological parameters using American Public Health Association standards methods (APHA, 2005). Among the parameters analyzed were temperature, dissolved oxygen (DO), pH, total dissolved solids (TDS), total suspended solids (TSS), 5 days biochemical oxygen demand (BOD_5) at 20°C, chemical oxygen demand (COD), ammonia nitrogen (NH_4-N), ortho-phosphate (PO_4-P), faecal coliforms (FC), total coliforms (TC). The samples were investigated in the water quality laboratory of environmental engineering department.

INDUSTRIAL WASTEWATER

The influent added to VFCW was wastewater from a local oil refinery. PVC valve fitted at the VFCW bottom was used to collect effluent samples every two weeks from October to December 2013. Wastewater samples were tested for various physical and chemical parameters using American Public Health Association standards methods (APHA, 2005). Among the parameters analyzed were turbidity, pH, total suspended solids (TSS), oil and grease, biochemical oxygen demand (BOD), chemical oxygen demand (COD), chloride, and total phenol. All parameters except phenol were analyzed in the Water Quality Laboratory of Department of Environmental Engineering NED University of Engineering and Technology.

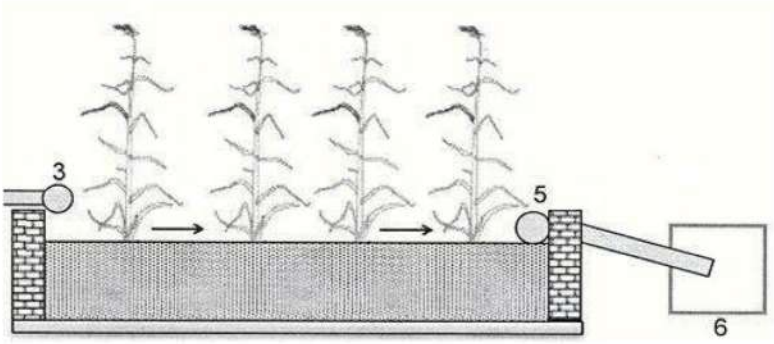

Figure 1: Free Water Surface Wetland (FWSW) for Treatment of Domestic Wastewater

Figure 2: Vertical Flow Constructed Wetland (VFCW) for Treatment of Industrial Wastewater (a) VFCW 1 planted with Phragmites (b) VFCW 2 planted with Typha

3. RESULTS AND DISCUSSION

WATER QUALITY IMPROVEMENTS BY FREE WATER SURFACE WETLAND

Table 2 represents the water quality improvements provided by the FWSW treating domestic wastewater The inlet TSS concentration to the FWSW was in the range between 95 - 350 mg/L while outlet TSS values were between 13 - 92 mg/L. The solids removal efficiency ranged from 73% to 86% with a mean reduction of 78%. In wetland systems, total suspended solids are removed predominantly through physical processes including settling and seizure mechanisms (Kadlec and Wallace, 2009).

The FWSW successfully stabilized organic matter. The BOD and COD concentration at inlet fluctuated between 32.5 -110 mg/L and 56 - 225 mg/L, respectively. After passing through the wetland cell concentrations for BOD and COD were in the range between 13-71 mg/L and 35-95 mg/L, respectively. The average reduction in BOD concentrations over the monitoring period was 50% with mean effluent BOD_5 concentration of 34 mg/L (Table 2). While the average reduction in COD concentrations over the monitoring period was 44% with mean effluent COD concentration of 68 mg/L (Table 2). The BOD to COD ratio was in the range of 0.55 to 0.27 confirming that organic matter was removed by the FWSW via biological degradation.

Nutrient removal by FWSW was good. The average inlet ammonia-nitrogen and ortho-phosphate concentrations

were 19.2 mg/L and 7.6 mg/L, respectively. The average ammonia-nitrogen and ortho- phosphate outlet concentrations were 9.7 mg/L and 3.7 mg/L. Ammonia-nitrogen reduction in the wetland system was 49% while ortho-phosphate reduction was 51%. Nitrogen compounds are transformed and eventually removed from the wetland system through processes like ammonia volatilization, nitrification and denitrification. The latter two are microbial mediated processes. In wetland systems, removal of phosphorus is through various processes including accretion, biomass storage, precipitation and sorption.

Analyses of indicator bacteria, total coliforms (TC) and faecal coliforms (FC) at the FWSW inlet and outlet showed that the wetland system efficiently removed both TC and FC. The mean removal rates over the monitoring period were in the range of 93 to 99%, showing a high efficiency of the constructed wetland system in removing the indicator bacteria. Mean concentration of TC at the wetland inlet and outlet were 2.1×10^6 counts/100mL and 8.0×10^3 counts/100mL, respectively (Table 2). While the mean concentration of FC at the wetland inlet and outlet was 1.1×10^6 counts/100mL and 3.0×10^3 counts/100mL, respectively (Table 2). In wetland systems, FC and TC are removed by various mechanisms including natural die-off and predation (Kadlec and Wallace, 2009).

Table 2. Mean influent, effluent concentrations and removal efficiency (RE) for Free Water Surface Wetland

S. No	Parameter	Unit	Intel	Outlet	RE (%)
1	pH	-	7.1	7.2	-
2	Dissolved oxygen	mg/1	1.7	4.5	-
3	TSS	mg/1	201	45	78
4	COD	mg/1	123	68	45
5	BOD	mg/1	69	34	51
6	Ammonia-nitrogen	mg/1	19.2	9.7	49
7	Ortho-phosphate	mg/1	7.6	3.7	51
8	Total coliforms	Counts/100mL	2.1×10^6	8×10^3	93
9	Faecal coliforms	Counts/100mL	1.1×10^6	3×10^3	98

WATER QUALITY IMPROVEMENTS BY VERTICAL FLO W CONSTRUCTED WETLANDS

Table 3 represents water quality improve ments provided by the VFCW treating industrial wastewater. The VFCW successfully reduced turbidity with good removal efficiencies of >90%; 91% for VFCW 1 and 95% for VFCW 2. Layers of gravel and sand packed in the pots facilitate filtration of the wastewater as it travels vertically downwards due to gravity. The mean inlet pH was 8.1while the mean outlet pH for VFCW 1 and VFCW 2 were 7.1 demonstrating the buffering capability of wetlands (Kadlec and Wallace, 2009). Table 3 shows that the two VFCW removed total suspended solids as well as oil and grease. Solids are generally removed through capture and settling (Kadlec and Wallace, 2009). Evaporation, leaching and sedimentation are physical processes that remove mineral oils in wetlands (Mashuri et al, 2000).

Table 3. Mean influent, effluent concentrations and removal efficiency (RE) for Vertical Flow

S. No	Parameter	Unit	VFCW 1	VFCW 2
			Intel	Outlet (RE %))	Outlet (RE %)
1	Turbidity	NTU	181	16.6 (91)	9.8 (95)
2	pH	-	8.1	7.1 (-)	7.1 (-)
3	TSS	mg/1	283	35.4 (87)	76.1 (73)
4	Oil and Grease	mg/1	1146	263.8 (77)	203.1 (83)
5	BOD	mg/1	328	208.1 (37)	211.7 (36)
6	COD	mg/1	746	320.2 (57)	309 (72)
7	Chloride	mg/1	34	1.3 (96)	0.6 (98)
8	Total phenol	mg/1	1.71	0.55 (68)	0.04 (97)

The mean COD removal efficiencies for the two VFCW were higher than BOD removal efficiencies. The nature of wastewater i.e. industrial wastewater is the possible reason for this difference. With regard to COD removal, VFCW 2 performed better than VFCW 1. While for BOD removal, VFCW 1 performed better than VFCW 2. This may be attributed to the different type of vegetation planted in the two systems i.e. VFCW 1 was planted with Phragmites while VFCW 2 was planted with Typha. Phragmites have roots extending to greater than > 1 m in the soil and assist in oxygen transfer which in turn support aerobic conditions and associated microbial degradation. Wetlands remove phenol through various processes including microbial degradation, plant uptake, sorption and volatilization (Imfeld et al 2009). However, for removal of phenolic compounds biodegradation is thought to be the most effective pathway (Liu et al, 2009). The reason for lower removal efficiency of VFCW 1 may be due to slow development of phenol biodegrading microbes in VFCW 1.

CONSTRUCTED WETLAND TECHNOLOGY FOR WASTEWATER TREATMENT IN KARACHI

The present centralized wastewater treatment systems treat only a fraction of total wastewater generated by the city. Further expansion of existing treatment plants is practically impossible because of no land availability. Moreover, wastewater from residential areas mixes with the

untreated industrial effluents and reaches the Arabia Sea via Lyari and Malir rivers. The beds of these rivers can be utilized to treat and reuse this wastewater. Constructed wetlands that are sustainable, low energy systems and low maintenance are considered to be an attractive alternative to conventional wastewater treatment plants. The results of the above study show that these systems can remove pollutants from domestic as well as industrial wastewaters. A study by Liu et al, 2008 compared the O & M cost of conventional wastewater treatment plants and constructed wetlands in China. They reported lower O & M costs US$ 0.0082 – 0.039 m^3/y for constructed wetlands as compared to US$ 0.1151 – 0.2465m^3/y for conventional wastewater treatment plants. If constructed wetland technology is properly designed and implemented it is probable that the wastewater treatment problem of Karachi can be sorted out on a sustainable basis.

4. CONCLUSIONS

Results show that constructed wetlands can successfully remove pollutants from domestic as well as industrial wastewaters in the environmental setting of Karachi. Discharge of untreated wastewater is a persistent problem afflicting people of Karachi and negatively impacting the associated ecosystems. Planning and commissioning of centralized energy and cost intensive wastewater treatment plants has proven unsuccessful not only in Karachi but also in other urban areas of the developing world. Alternatively, constructed wetlands can be applied as a sustainable, low cost and low energy technology for solving the wastewater treatment problem.

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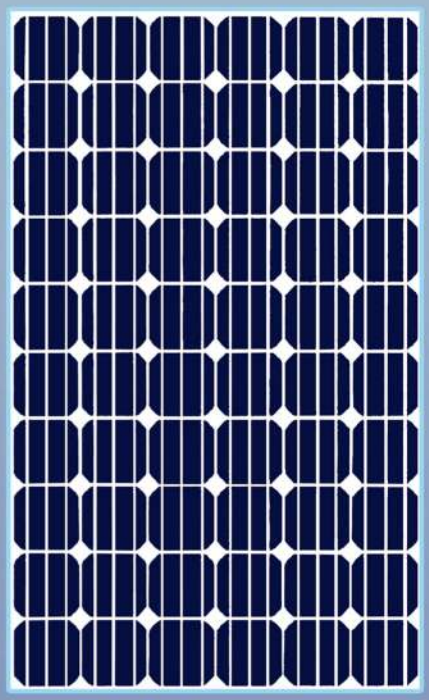

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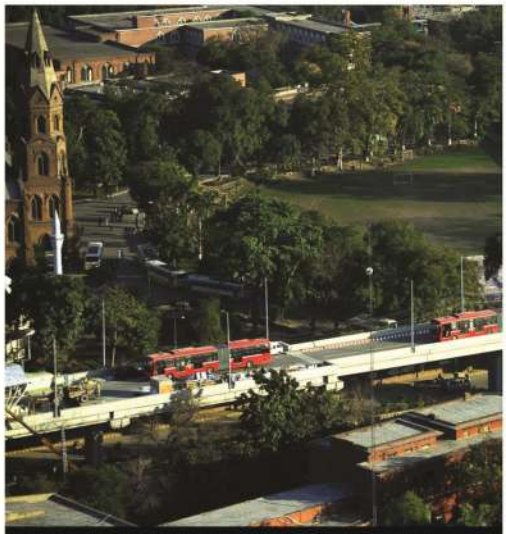
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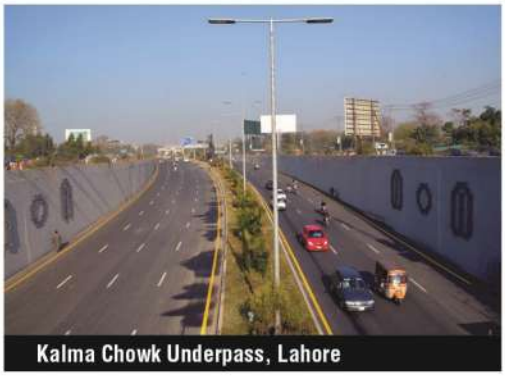
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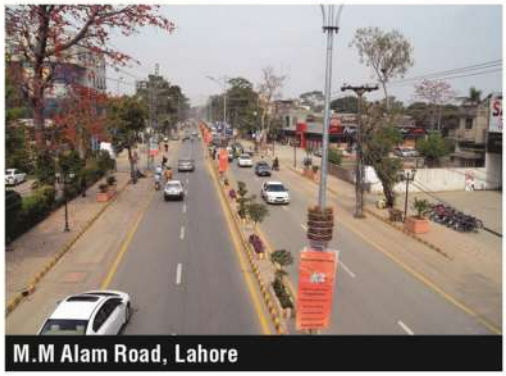
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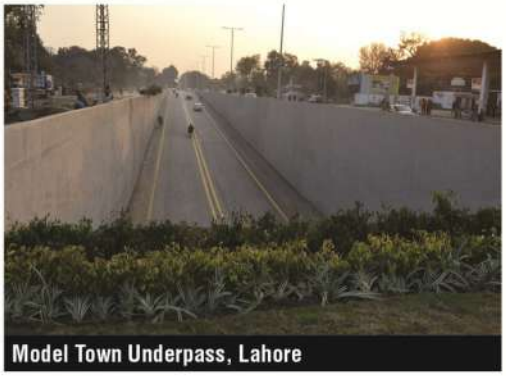
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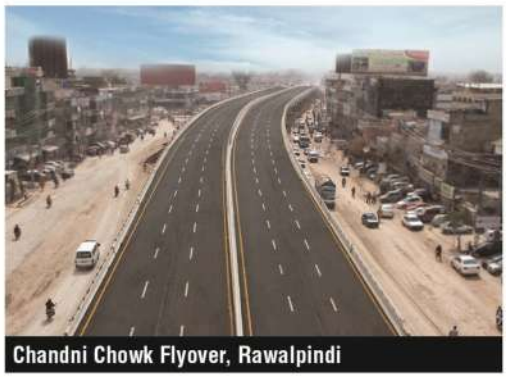
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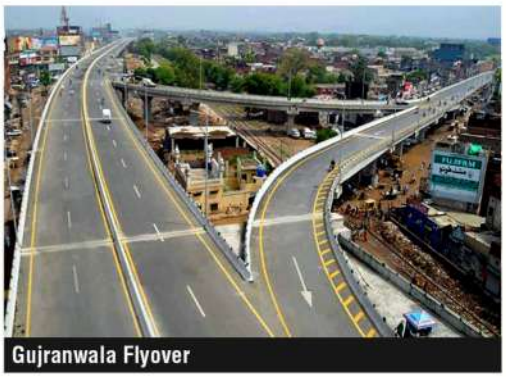
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