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REPORT

ICS-UNIDO
AND
UNIVERSITY OF CAPE COAST
DEPARTMENT OF PHYSICS

On

"COMBUSTION DIAGNOSTICS AND OPTICAL TECHNIQUES"

Held at

LASER AND FIBRE OPTICS CENTRE
CAPE COAST, GHANA

And

COCONUT GROVE BEACH RESORT,
ELMINA, GHANA

5TH-10TH JULY, 1999

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FOREWORD

This report is a true account of the organisation of the Workshop and reflection of what was recorded before, during and after. The Workshop on Combustion Diagnostics and Optical Techniques was held on 5-10 July, 1999 in Cape Coast.

Most summaries of the group discussions and speeches were prepared by the Chief Rapporteur, Mr. S. Akoto Bamford while the evaluation report and analysis were done by Dr. A. Owusu.

The structure of the course, both the scientific and laboratory sessions concluding remarks and project topics were summarised by the local organiser, Dr. P. K. Buah-Bassuah.

The National Organising Committee gave the necessary suggestions to get this volume in its rightful order.

Thanks are due to Mr. P. K. Mensah for reading through this manuscript. We are most grateful to the secretarial staff most especially Ms. Ellen Osekre, for coming out with the final manuscript. Thanks are also due to Ms. Doris Osei, Mercy Yaadar, Gertrude Quansah and Regina Eshun for their various roles they played in the preparation of this report.

P. K. BUAH-BASSUAH
LOCAL ORGANISER

EXECUTIVE SUMMARY

Thanks to the many sponsors, the Workshop began with the arrival of some foreign lecturers and participants in Accra on Friday, 2nd and Saturday 3rd July, 1999. With the assistance of the Public Relations staff of the Ghana National Petroleum Corporation, guests were received at the airport and subsequently transported to Cape Coast by vehicles provided by the Tema Oil Refinery and University of Cape Coast.

On Sunday the 4th July, an excursion to the Kakum National Park and to the Cape Coast castle was organised for the foreign guests.

The opening ceremony, in the morning of the 5th July, was chaired by Mr. W. S. Parker, the chief Executive of Tema Oil Refinery and attended by three Ministers of State - the Central Regional Minister, the Minister of Environment, Science and Technology, and the Minister of Mines and Energy, who also delivered the keynote address. Also in attendance were the Vice-Chancellor of the University of Cape Coast, Deans of Faculties, Heads of Institutions and Departments and graduate students from the country's universities.

The Workshop itself was attended by ten (10) lecturers, one each from the United Kingdom, Hungary and Egypt and two each from France and Italy. The other three were Ghanaians. There were sixty (60) participants in all, including twenty (20) graduate and undergraduate students from the Kwame Nkrumah University of Science and Technology, Kumasi and the University of Cape Coast. The foreign participants were from Morocco, Rwanda, Sudan, Cote d'Ivoire, Nigerian and Senegal.

The scientific programme itself included lectures (25 invited papers and case studies), practical sessions at LAFOC, and field trips to the Volta Aluminium Company and the Tema Oil Refinery. The main presentations focused on the following topics:

Modeling of combustion diagnostics
Laser probing of combustion
Optical measurement methods
Absorption and emission spectroscopy
Air pollution due to combustion.

In the evening of the 5th of July, a cocktail party was held at the Vice-Chancellor's lodge. A conference dinner was also held in the evening of 6th July, in honour of the lecturers and participants. In attendance was the Fire Angels Band from the Regional Fire Service.

At the end of the Workshop, a resolution was passed and forwarded to the press and all stake holder institutions. The closing ceremony was chaired by Prof. Kobena Yankson, Dean of the Faculty of Science of the University of Cape Coast. The special guest at the ceremony was Mr. Tsatsu Tsikata, the Chief Executive of the GNPC who challenged participants to follow up the week's deliberations with some practical problems.

In all, each of the sub-committees and the secretarial staff worked very hard to make the Workshop a big success, as ascertained by the participants. The Coconut Grove Beach Resort also provided excellent facilities for the Workshop - accommodation, meals and conference room.

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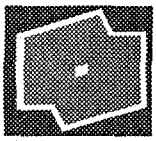
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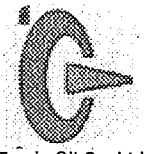
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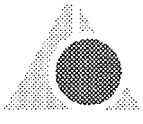
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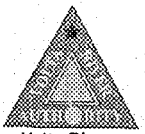
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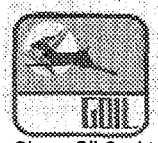
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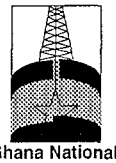
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PRESS RELEASE

ICS INTERNATIONAL WORKSHOP ON COMBUSTION DIAGNOSTICS AND OPTICAL TECHNIQUES COCONUT GROVE BEACH RESORT, ELMINA 5-10 JULY, 1999

The International Workshop on Combustion Diagnostics and Optical Techniques to be held in Sub-Saharan Africa, Ghana on 5th to 10th July, 1999 is a follow-up of an Expert Group Meeting organised by the International Centre for Science and High Technology {ICS-UNIDO} in Trieste {Italy} in June, 1998.

The workshop is opened to scientists, researchers, engineers, environmentalists from universities, research institutes, industries and government agencies in Africa. In all, sixty participants would be coming from Algeria, Rwanda, Nigeria, Cote d'Ivoire, Ghana, Senegal, Sudan and United States of America. Lecturers engaged in this workshop are coming from the United Kingdom, France, Ghana, Italy and Hungary.

The workshop aims at promoting closer links between industries and research institutions; providing the know-how of optical and imaging diagnostics of on line monitoring of plant performance, encouraging the exchange of ideas between experts in developed and developing countries; creating awareness in combustion systems and the consequence of their emissions. In order to fulfill the above aims, plenary lectures would be given and practical sessions would be organised. In addition, the workshop will examine the current activities and future prospects of Optical Physics in both pure and applied research.

This international workshop is being organised by International Centre for Science and High Technology, ICS and UNIDO in collaboration with Tema Oil Refinery, Ghana National Petroleum Corporation, Volta River Authority, Volta Aluminium Company, Department of Mechanical Engineering of Kwame Nkrumah University of Science and Technology and also Laser and Fibre Optics Centre, University of Cape Coast.

The theme of the workshop, **Combustion Diagnostics and Optical Techniques**, tends to suggest that various topics on combustion system would be discussed and the use of optical methods to monitor the performance of the combustion process, also considered.

Combustion processes include small and large scale reactors, steady and unsteady processes, atmospheric as well as pressurised units, representing all kinds of industrial equipment from large furnaces in power generating plants, to small in-house burners for heating, gas turbines, automotive and aircraft engines, aerospace propulsion devices, and even undesired combustion processes such as fires and explosions.

Major activities in combustion systems for stationery sources (thermal plants, industrial processes, fuel combustion) and dynamic source (transportation) tend to be dictated by the following parameters such as:

a. fuel formulation

b. engine refinements

c. age of combustors and burners

d. flame characterisation

e. efficiency in energy conversion.

Most stationery internal combustion engines are used to generate electric power, to pump gas or other fluids, or to compress air for pneumatic machinery. Smaller uses include irrigation, mining and hoisting and nuclear power plant emergency cooling water pump operation. Vehicular movements also do cause emissions of some gases.

The major emissions associated with such combustion systems include oxides of sulphur, carbon monoxide, particulate matter (dust, smoke, fly, ash, mist); hydrocarbons (hexane, benzene, methane butane etc) oxide of nitrogen, hydrogen fluoride. The Poly-aromatic hydrocarbon (PAH) pollution in air on the other hand, have some health hazards to the populace.

Monitoring such gases, however, provides accurate emission data, data input for modeling and information about plant performance.

We realise from the foregoing that the useful energy being produced has some pollution-related issues associated with it. There is therefore the need to undertake programmes aimed at diffusing awareness of the pollution consequences due to an increasing energy demand. This awareness should be stimulated at the level of advanced experts of technology and managers of the wider economy of the nation.

The ultimate goal therefore is to provide steps towards higher efficiency and less polluting combustion systems. This process requires the development of local expertise in combustion control for keeping in a correct operation the already existing plants; as well as for upgrading and retrofitting of old installations. It is also needed to develop a research field which could address the development of instrumentation using high technology to assess the health effects of exposure to PAH pollution in air particulates.

In order to be abreast with such problems and be in a position to solve them, it is essential to concentrate on measures for the prevention, or at least the limitation of pollution towards optimisation and improvement of the used combustion equipment and technologies. It is sad however, to note that though industries and mines in Ghana have the will to undertake such measurements, there is lack of equipment to monitor the gas releases.

The workshop has been able to identify various methods of monitoring the combustion processes. Some of the emissions from these industries are inaccessible and as such the use of traditional monitoring techniques seem to be inadequate. Optical diagnostics, which induce minimal perturbation to a system and pursues non-contact

probing provides information with high sensitivity and selectivity. There is the urgent need to explore other techniques that have no constraints in terms of access to the source of pollutants. In this regard, laser techniques represent a possible alternative for the detection, and monitoring of gases (in high temperature regime) from combustion systems for improved efficiency and good performance. The laser measurement and probing techniques depend on emission and absorption spectrometry, and laser induced fluorescence.

The workshop is therefore seeking for possible redress to these emission problems by linking up with institutes such as Environmental Protection Agency (EPA), Centre for Scientific and Industrial Research (CSIR), Energy Board and the universities to come out with projects for our national development.

We are also aware that in Ghana, major air pollutants are currently not effectively monitored. The reason may be technical or logistics. The workshop has therefore provided a forum for all avenues of improving upon monitoring systems, and for identified drawing of research to ensure clean combustion technologies as Ghana gradually develops industrially. The two industrial cities at Tema and Takoradi and the capital, Accra should consider effective ways of controlling atmospheric pollutants. In addition activities in mining towns like Obuasi and Tarkwa should be closely monitored to ensure improved efficiency in energy conversion and clean environment.

Research work has been going on in our cities and industrial sites and we hope that a consensus will be reached at this workshop to have a better co-ordination among scientists, technologists and researchers to work towards achieving cleaner combustion systems. The workshop is therefore looking forward to initiating programmes to have NOx combustion controls, and optimised combustion operation to regulate ozone and acid rain effects. Other options for combustion controls based on selective catalytic reduction and selective non-catalytic reduction would be considered. Ironically, greater control on NOx emissions increase the emissions of carbon monoxide and carbon dioxide. The release of such gases in greater quantities (green house effect) has caused climactic variations leading to global warming.

The workshop is expected to deliberate on most of these issues and seek for redress to make our environment a comfortable place for human habitation.

National Organising Committee

INTRODUCTION

In April, 1997, Prof. G. Denardo from the International Centre for Science and High Technology, Italy, visited the University of Cape Coast. In his desire to link up activities of the Regional Laser and Fibre Optics Centre (LAFOC) at University of Cape Coast with Industries, discussions were held with the Chief Executive of Tema Oil Refinery Limited (TOR). As a first measure, two Ghanaians, Dr. P.K. Buah-Bassuah of University of Cape Coast and Dr. Abeeku Brew-Hammond of Kwame Nkrumah University of Science and Technology were nominated to attend expert group meetings on combustion in Trieste, Italy in June 1998 and March 1999. At the first group meeting in 1998, it was recommended that a workshop on combustion be organised in one of the represented developing countries. Ghana was chosen to host this workshop.

The workshop on "Combustion Diagnostics and Optical Techniques" held at Cape Coast, Ghana, 5-10 July, 1999, is therefore a follow-up activity based on recommendations made at an ICS-UNIDO expert group meeting on combustion, held in Trieste, Italy, 1-5 June, 1998.

The objectives of the workshop are:

i. to promote closer links between universities/research institutions and industry;

ii. to provide the know-how of optical and imaging diagnostics for non-invasive, on-line monitoring of plant performance;

iii. to create awareness in combustion systems, and the environmental consequence of their emissions;

iv. to encourage the exchange of ideas between experts in developed and developing countries.

The rising demand in energy for industries and domestic activities has put an increasing burden on the energy production sectors. This has led to the construction of additional power plants with their attendant combustion processes and emissions into the atmosphere. There is therefore the need for scientists and engineers to be equipped with the knowledge and skills of proven diagnostic tools such as laser and optical techniques. Optical diagnostics induces minimal perturbation to a system and provides information with high sensitivity and selectivity.

The invited lecturers and other presentations made at the workshop covered the following topics:

- Modeling of combustion diagnostics
- Laser probing of combustion
- Optical measurement methods
- Absorption and emission spectrometry

- Air pollution due to combustion.

Laboratory sessions also covered:

- Imaging of flame to determine OH spectra
- Laser Doppler Velocimetry (LDV) to monitor spray droplets
- Mach Zhender interferometry to monitor flame from bunsen burner
- Soot absorption
- Flame emission spectroscopy.

Field trips were also made to Volta Aluminium Company (VALCO) and Tema Oil Refinery (TOR).

SPONSORS OF WORKSHOP

The workshop which was held in Cape Coast is the first of its kind in Sub-Saharan Africa and we would like to thank ICS and UNIDO for providing approximately $31,000 being 50% of the cost of the workshop. This was spent on foreign participants and lecturers. The remaining 50% of the cost has been provided locally by stakeholders such as Tema Oil Refinery, Laser and Fibre Optics Centre, Kwame Nkrumah University of Science and Technology, University of Cape Coast, Ghana National Petroleum Corporation, Volta Aluminium Company Limited, Volta River Authority, Ghana Oil Company Limited, Mobil Oil, Shell, Elf, Total, Unipetro, Engen Petroleum Limited, Tropic Oil Company, Allied Oil Company Limited, Star Oil Company Limited, Ghana Automobile Distributors Association, Tema Power Company Limited and Motherwell Bridge Ghana Limited.

PARTICIPATION

The workshop was attended by ten [10] lecturers, one each from the United Kingdom, Hungary and Egypt and two from France and Italy with three from Ghana. There were sixty [60] participants from Africa with the regional participation as follows:

Twenty {20} undergraduate and graduate students attended the course as well from Kwame Nkrumah University of Science and Technology, Kumasi and University of Cape Coast, Cape Coast.

Participants	Number	Lecturers	Number
Morroco	1	United Kingdom	1
Rwanda	1	France	2
Sudan	2	Italy	2
Cote d'Ivoire	4	Hungary	1
Nigeria	3	Egypt	1
Senegal	1	Ghana	3 {10}
Ghana	47 {60}		

OPENING SESSION

The opening ceremony of the workshop which took place at the Coconut Grove Hotel, Elmina (near Cape Coast) on 5th July, 1999, was attended by three (3) Ministers of State. These were the Minister of Central Region, the Minister of Environment, Science and Technology and, the Minister of Mines and Energy.

Also in attendance were the Vice Chancellor of University of Cape Coast {UCC}, Deans of Faculties, some Faculty members of the UCC, foreign lecturers, participants and invited guests.

The Chairman for the occasion was the Chief Executive of Tema Oil Refinery {TOR}, Mr. W. S. Parker. The welcome address was given by the Vice Chancellor, Prof. S. K. Adjepong of UCC, and short addresses were also given by a representative of ICS/UNIDO, {Dr. Miltcho Danailov}, the Regional Minister, {Lt. Col. C. K. Agbenaza (rtd)}, the Minister of Environment, Science and Technology, {Hon. Mr. C. Avoka}. The keynote address was given by the Minister of Mines and Energy {Hon. Mr. Ohene Kena}. From these addresses the sum total of their expectations from the workshop includes:

- forging partnership between institutions of higher learning and industry
- formulating projects to evaluate plant performance of combustion systems, and monitor emission from combustion
- improved combustion efficiency through better burner designs , and alternate fuel-mix options
- strategies for the implementation of climate change convertion
- pooling of resources to facilitate comprehensive monitoring of combustion emissions.

At the end of the opening ceremony, the dignitaries and invited guests visited LAFOC to see the experiments that have been set up in the laboratory for hands-on experience in optical techniques.

ORGANISATION OF THE WORKSHOP

The workshop was organised by a National Organising Committee (NOC) out of which various sub-committees were formed to deal with some aspects of the workshop. These sub committees namely; Manciple, Technical, Publicity - Protocol, Advisory and Secretarial. Mr. W.S. Parker, Chief Executive of the Tema Oil Refinery Limited was the chairman for the NOC.

On Sunday, the 4th of July, visits were organised to the Kakum National Park, a Forest Reserve area 40 kilometers from Cape Coast. In the afternoon, visits were made to the historic castle at Elmina.

During the weekdays, from 5th July to 10th July, 1999, lectures and practical sessions were organised. In the evening of the 5th July, a cocktail was organised at the Vice Chancellor's lodge as a means of socialising with the invited participants, lecturers and University dons. A conference dinner was held on the 6th July, 1999 at the evening in honour of the lecturers and participants. On the evening of 7th July, a cultural troupe from Cape Coast Centre for National Culture was invited to entertain participants with local tunes and traditional Ghanaian drumming and dancing.

An educational trip was also organised on the Thursday 8th July, 1999 to two industries at Tema, 200 km from Cape Coast, where oil is refined and aluminium is smelted. Various practical exposures on combustion were seen and observed at the industries. On Friday, 9th July, 1999 a round table conference was organised before the start of the day's scientific session. Reports from various groups were analysed out of which a communique of the workshop was drafted. The closing ceremony was done at 14.00 of 10th July, 1999 by the Chief Executive of the Ghana National Petroleum Corporation. All the participants left on the next day for Accra, 160km from Cape Coast. The workshop was highly advertised as all the activities were covered by the local newspapers and the National Television network.

THE STRUCTURE OF THE TRAINING COURSE

The training course included lectures and practical sessions. In all twenty-five invited and contributed papers as well as case studies were presented. The morning sessions and one hour of the afternoon session each day were devoted to lectures while the rest of the afternoon sessions were devoted to the practical work of at the laboratory.

SCIENTIFIC SESSIONS

The scientific sessions comprised of invited lectures, contributed papers, case studies, group discussions and laboratory sessions. The subject areas of the lectures and presentations can be put into three main categories:

1. **Laser and Optical Techniques** (including):

   - optical interaction processes of absorption, emission, fluorescence, elastic and inelastic scattering

   - principles of the optical diagnostic methods of Laser Induced Fluorescence (LIF), Coherent Anti-Stokes Raman Scattering (CARS), Degenerate Four Wave Mixing (DFWM), Induced Gratings, and Polarization Spectroscopy (PS)

2. **Combustion** (including):

   - understanding combustion processes through experimentation, numerical simulation and computer modeling

- laminar and turbulent flames

- analysis of flow fields of turbulent flames using laser Doppler Velocimetry (LDV) and Particle Image Velocimetry (PIV)

- measurement of temperature and species concentration in flames of domestic gas appliance using emission Fourier Transform Infrared Spectroscopy.

3. **Emissions** (including):

   - chemistry and flow structure interaction

   - optical remote sensing techniques of Differential Optical Absorption Spectroscopy (DOAS) and Differential Absorption Lidar (DIAL).

   - LIDAR Dial system for the detection of hydrocarbon pollution in the atmosphere

   - NO_X removal in a plasma discharge system

   - vehicle exhaust emission diagnosis.

The laboratory sessions gave practical exposure and hands-on skills in

i. spectroscopy of flame emission for the purpose of specie measurement

ii. gas detection by absorption spectroscopy using temperature tuned laser diode

iii. determination of soot volume fraction by optical extinction

iv. flame diagnostics by light sheet imaging and by shearing interferometry

v. velocity measurement in water spray droplets using laser doppler velocimetry.

The papers presented have been divided under the following themes:

- Combustion systems and modeling
- Monitoring processes
- Optical Diagnostics and measurement
- Laser techniques in combustion and flames.

The papers are hereby summarised with the main points highlighted which form the basis for the development of the project proposals.

PRESENTATIONS

A. COMBUSTION SYSTEMS AND MODELING

COMBUSTION: What is it ?
F. O. Akuffo

Fundamental concepts in combustion and its applications in key economic activities were presented.

Combustion is derived from fuel air mixture that is accompanied by flame and the release of energy as heat. Materials such as solid fuels and gaseous fuels for combustion were outlined and various uses in the energy sector were given. The sources of energy were explained and the sources of gaseous emissions derived from economic activities for Agricultural, Vehicular and Industrial practices were also shown.

COMBUSTION MODELING
Abeeku Brew-Hammond

Various analytical problems on combustion were reviewed using the enthalpy principle. By making use of input parameters such as the enthalpy of reactants, temperature and enthalpy of products values, the various gaseous species with the energy values were given. These calculations were done with application to flames from fuel and power generation from gas turbine with specific practical reference to the Takoradi Thermal Power Plant. Various graphical plots were given in terms of power output versus mass flow rate of fuel and also of thermal efficiency versus ambient temperature.

TURBULENT COMBUSTION AND MODELING
D. Veynante

Turbulent combustion occurs where mass and heat transfer are higher and more efficient. By applying classical Navier-Stokes, species and energy transport equations in reactive flows, laminar flames and effect of turbulent motions on combustion can be studied. Major properties of premixed flames were also presented using the unsuccessful Taylor's expansion of the mean reaction rate for physical analysis to develop turbulent combustion diagrams. Available Modeling techniques such as Reynolds Averaged Navier-Stokes (RANS), mean reaction rate and turbulent transport modeling were used to derive different turbulent combustion models for different formalism. A new approach of simulation called Large Eddy Simulations (LES) was used as potential candidate to predict combustion instabilities.

IMPROVEMENT OF THE MODELING OF INDUSTRIAL FURNACES AND PROCESSES FOLLOWING EXPERIMENTAL OBSERVATIONS

J. P. Martin

An expanded perlite rock with good thermal and sound properties has been found to be a good candidate to be used as a building and construction material in industrial furnaces. Owing to its uniform density and well controlled size distribution, computer code has been written to predict the combustion required for the expansion process and the particle trajectories of perlite rock being used as a material inside a vertical industrial furnace to serve as improving the quality of the final expanded product and also optimising the energy consumption inside the furnace. By regulating the combustion parameters such as temperature, velocity and concentrations of CO2, the results of the code was tested in order to have reliable values for the description of the initial flow field in the burner and the furnace.

B. MONITORING PROCESSES

MONITORING PROCESS IN AIR POLLUTANTS FROM COMBUSTION

P.K. Buah-Bassuah

Combustion systems can be derived from both internal combustion engines and external combustion sources. Most engines for electric power generation, compressor drives, mobile refrigeration units, industrial plants, aerial and fork lifts including vehicles and aircrafts make use of these engines.

The operation of these engines in Ghanaian Industries, such as the mines and the oil refineries emit pollutants even though various measures have been taken to minimize them. Emissions therefore from various industries in Ghana were therefore outlined and the traditional techniques used to monitor them explained. However, in view of some of the long stacks and inaccessible nature of them, various laser techniques were enumerated to serve as an alternative means of having on line and real time monitoring of the emissions.

NEEDS FOR OPTICAL MEASUREMENTS IN COMBUSTION PROCESSES FOR ENERGY EFFICIENCY IMPROVEMENT AND POLLUTION ABATEMENTS

J.P. Martin

An approach has been made to validate results of modeling by making use of optical diagnostics to deal with the flow field, temperature, stable molecules and radical concentration. Laser Induced Fluorescence (LIF) measurements at different pressures have been made using OH detection to trace the flame location in a burner. In addition, this method is being applied to finding pollutant (NOx and CO) formation in a water heater gas appliance. Interaction of a plane acoustic wave with a laminar premixed flame and super imposed with sinusoidal plane acoustic wave and pressure modification which however increase the burning rate. Such tests are to give systematic studies of diffusion rate of hydrogen in air in the flames.

AETHLOMETER APPLICATIONS FOR REAL LIVE MONITORING OF COMBUSTION DERIVED AEROSOL CARBON
F.A. Akeredolu

Elemental carbon can be measured using effective optical techniques such as Raman spectroscopy, absorption measurements, aethalometer, thermal methods and photo acoustic techniques. All the above methods, with the exception of the aethalometer grab sampling and time-lag before the carbon concentration is determined. Aethalometer monitors real-time emissions of elemental carbon using the absorbance of elemental particles that are transformed into voltage signal and detected by photo-multiplier into a data logger into the computer for processing. The elemental carbon concentrations are derived from the voltage measurements.

OPTIMIZATION OF NOx REMOVAL BY NON-THERMAL PLASMA DISCHARGE SYSTEM
Yaw Yeboah et al

Non-thermal Plasma Discharge NTPD has been identified as a promising candidate for NOx removal. In order to optimize a NTPD for NOx removal, possible parameters such as effects of discharge gap width, input power, fuel gas composition, and residence time on the electrical processes that occur in a dielectric barrier discharge are applied. In this, divide the electrical energy coupled to the gas is used for the production of energetic electrons, leaving the background gas at ambient temperature. The energy in the plasma is thus directed preferentially to electron - impact dissociation and ionization of the background gas to form free radicals. These free radicals react chemically with the surrounding molecules to produce compliant effluent. It thus provides energy selectivity and the capability to simultaneously remove several pollutants.

Measurements taken were the breakdown voltage, NOx removal and micro discharge observations Physical considerations suggest that for larger gap widths the reduced electron energy, charge density and spatial coverage of the micro discharges limits effectiveness while at smaller gap widths the reverse trends lead to intensification of processes that adversely affect NOx removal.

C. OPTICAL DIAGNOSTICS AND MEASUREMENT

OPTICAL MEASUREMENTS
P. Mazzinghi

Optical diagnostics are used for the understanding of combustion processes and the detection of combustion products. The technique which is related to the minimal perturbation induced to the system using non-contact probing allows measurement in extreme temperature, pressure, and chemical environment, as found in flames and all other combustion processes. Such methods include emission, absorption, fluorescence, elastic and inelastic scattering and could be done by using a tunable diode laser. It is also noted that such methods could be extended to monitor the environment using optical remote sensing called the Differential Optical Absorption Spectroscopy (DOAS) and the Differential Absorption Lidar (DIAL).

D. LASER TECHNIQUES IN COMBUSTION & FLAMES

PRINCIPLES OF LASER DIAGNOSTICS FOR COMBUSTION
P. Ewart

Combustion parameters such as temperature and species concentration could be measured by using physical principles such as Laser Induced Fluorescence, coherent Anti-Stokes Raman Scattering, Degenerate four wave mixing and related laser induced grating methods together with Polarization Spectroscopy. The techniques which are non contact can probe into flame and engines relying mostly on both the spontaneous emission of radiation from laser excited molecules and coherent interactions to produce laser-like signal beams. The advantage of the techniques is that it measures low concentration in parts per billion as well as major or minor constituents of species.

LASER-BASED MEASURING TECHNIQUES OF FLOWS, SPECIES, CONCENTRATION AND DENSITY
Mohy Mansour

The use of scattered Rayleigh signal to monitor temperature and density of gases based on the principle of Rayleigh cross-section has been effective in combustion diagnostics. The intensity of the Rayleigh signal is detected at 90° to the laser beam. The temperature of the hydrocarbon flame can be obtained using the Rayleigh cross-section of the flow. In order to measure radicals that occur at higher temperatures, laser induced fluorescence and laser induced predissociation fluorescence in the flame is used. Raman scattering, on the other hand, is used to measure simultaneously species concentration of major and intermediate radicals of the flame. The detected signal is spectrally dispersed using a monochromator. Laser Induced Incandescence (LII) is also a good technique in measuring soot particles. LII is produced when the soot particles absorb the energy provided by the laser and heated to high temperatures.

PARTICLE IMAGE VELOCIMETRY AND LASER DOPPLER VELOCIMETRY IN COMBUSTION SYSTEMS
Yaw Yeboah

Particles Image Velocimetry (PIV) provide information on flow visualization and associated structures such as velocity map, stream lines and velocity in flame diagnostics. However Laser Doppler velocimetry gives point velocity measurement over time. Using different nozzle dimensions in a combustor to make different sizes of flames from (methane-air ratio) the image was controlled through a PIV image processor interface into a computer after each Laser pulse has been fired. The emissions from the combustors were also characterized.

The Laser Doppler velocimetry was used to study an axially forced turbulent premixed methane - air jet flame using high-speed video imaging. Scattered light from particles passing through the probe volume has a Doppler frequency which is proportional to

the particle velocity. Such probe volumes are imaged when the multi-colour argon-ion laser are used through the flame of free - falling burning droplet. High speed images of droplet gasification and combustion provided better understanding of the droplet behaviour in sub and supercritical pressure environments. The combustion process of a free droplet including ignition under different conditions, such as pressure and temperature were analysed.

LIDAR DIAL SYSTEM FOR THE DETECTION OF HYDROCARBON POLLUTION IN THE ATMOSPHERE

T. Gasmi

A DIAL system was designed to measure ethylene, ammonia emissions that has effect on the ozone. Long path integrated measurements of the pollutants were made and using some selected targets various analyses of such pollutants were evident.

CASE STUDIES

COMBUSTION PROCESS IN OIL REFINERY

K.K. Ditsa et al

The Oil Refinery of Tema refines and distill fuel into LPG, Vergin Naphta, S.R. Kerosene, Gas Oil and Reduced Crude. The refinery has its own two steam turbine generators abated at 1.3 MW to satisfy its additional power needs. Possible combustion systems include boilers and furnaces. The boilers use fuel gas and fuel oil whilst the furnace heat the crude oil to its distillation units giving the minimum pollutants to the atmosphere.

Though air-fuel ratio are ensured this is manually operated to attain the required specification. In all the process NOx formation is inevitable despite several attempts to control the combustion process. In addition the refinery monitors the steam/air atomization flame quality and the viscosity of the oil to regulate and minimise the emission of pollutants. Many monitoring sites have been created to see the effects of emissions on the townships.

The refinery will like detail studies to be made in the flare coming out of the stacks using possible techniques that is laser based to get to such inaccessible points.

COMBUSTION PROCESS AT VALCO

E. K. Avotri

Volta Aluminium Company makes use of seven charging melting furnaces and three holding furnaces. The combustion process make use of air-fuel ratio for better combustion. The smelter of the aluminium releases gases such as NOx and HF to the atmosphere. These gases are emitted through the stack. There is the need to use a Laser-based technique to do on line monitoring at these stacks even though VALCO has the capability of monitoring some of the emitted gases by other methods.

TAKORADI THERMAL POWER PLANT

S. K. Doku

Power is generated using the burning of light crude oil as well as natural gas into the combustor of the gas turbine. Combustion takes place in the combustor when a stream of atomized fuel gas is ignited. Flame stability and temperature depends on the fuel to air ratio. Because of the temperature limitations of the materials used for construction of the combustor and the hot gas path parts, it is impossible to allow the flame to achieve the full temperature.

Products of combustion of fuel in the gas turbine produces CO2, CO, NOx and oxides of sulphur and particulates though some control strategies are employed in the industries. Since there are no available equipment to effectively monitor these gases, the actual level are not known. However there is a problem of monitoring gases from stacks due to the height. It is therefore essential to look for laser-based techniques to remotely monitor these emissions.

COMBUSTION PROCESS MONITORING BY ENVIRONMENTAL PROTECTION AGENCY

D.J. Jumpah

Emissions from vehicular and industrial processes are of great concern to both plant and human activities. The major pollutants from these emissions are oxides of Nitrogen, sulphur, carbon, many volatile organic compounds hydrocarbons, trace metals and other particulates. However, the main source of carbon monoxide in Ghana is from road transport. The estimates in metric tonnes of emissions from the transport sector are not yet available. This needs to be done so that the proportional contributions from the various combustion processes could be determined, impacts adequately predicted and addressed.

In addition, most of the air-borne emissions of lead arises from petrol engine motor vehicles since only leaded fuel is available in Ghana. The presence of lead exhibits adverse effects on human health.

Monitoring techniques of Environmental Protection Agency fall in four main categories using the traditional methods. These equipment are used in the industries, on roads and busy cities to measure the pollutants.

Results from monitoring stations indicate that the mining zones have much dust pollutants exceeding the required levels as well as air pollutants in the commercial and residential areas more than the industrial area itself. Other measures being taken to regulate pollutants from vehicles are going to be initiated by using metered smoke test.

Environmental Protection Agency therefore recommends that application of laser techniques in the National air quality monitoring and air pollution combustion pollutants modeling should be encouraged.

POLLUTION FROM MOTOR VEHICLES IN GHANA
K. Anaman

Emission from vehicles, namely oxides of nitrogen, carbon monoxide, unburned hydro-carbons, particulates (ash and soot) come under anthropogenic sources. Emission control methods therefore require increasing the air-fuel ratio and recirculating part of the exhaust through the cylinders to reduce the CO and HC output and also control the NOx. In addition a good engine design measures as well as exhaust gas treatment tend to reduce the emission requirements. Reducing vehicular emissions in Ghana require more fuel-efficient vehicle, less polluting fuels and through increased use of mass transit systems. Since most Ghanaians use vehicles within the ages of 6 - 12 years, the pollution levels are high with high fuel consumptions.

It is being proposed that public transport such as (buses, taxis) should run on diesel engines for higher efficiency, low fuel consumption and last longer and reduce vehicular pollution. Another recommendation is to make use of more environmentally friendly fuels such as liquefied petroleum gas (LPG), alcohol, and hydrogen. Legislation on exhaust emissions require progressive reductions to be made in HC, CO, and NOx content of exhaust gas from vehicles.

LABORATORY SESSIONS

Four {4} groups were made each comprising seven {7} participants. The groupings and laboratory schedule are included under this section.

- **The spectroscopy of flame emission from a bunsen burner** helped the participants to identify excited OH, C2, and CH molecules. The spectra of the flame was visually viewed from the monochromator.

- **Absorption spectroscopy of Rb87 using a tunable diode laser** was set up to demonstrate the absorption lines of the vapour phase metal which was contained in a sealed cell at a fixed pressure and temperature. The study enables one to measure the hyperfine structure of the natural rubidium.

- **Determination of soot volume fraction by extinction method.**
  The experiment presented an optical determination of the amount of soot in flames. It was based on a measurement of the transmission of a laser beam crossing the studied flame. By making use of expression of extinction coefficient and the optical path in the flame, the soot volume fraction could be evaluated. The value obtained by this measurement is integrated over the length of the path in the flame. Horizontal measurements were done in different flame zones. If a horizontal scanning is performed and absorption versus transversal position is measured, one can obtain the real soot distribution by performing Abel transform of the measured data.

- **Velocity measurement in a spray using Laser Doppler velocimetry.** In combustion analysis, it is frequently needed to map the velocity distribution of the flow of the fuel, the oxidant, or other components. The basic physical principle is to measure the frequency shift of a laser light scattered and the original beams, or using differential measurement of the relative shifts of two probe beams which intersect the flow field in different directions forming fringe pattern.

  When moving particle such as the drop crosses the fringes, a periodic dust of scattered light is given which is then collected by a detector. If the particle size is small, the scattered light intensity becomes too low; if the particles are larger than the fringe separation, the available signal has a small modulation.

  Depending on the regulation of the spray, different frequency distributions with peaks in the range 400-900KHz are observed; with the observed bandwidths as wide as 100-300KHz.

- **Flame diagnostics by light sheet imaging and by shearing interferometry.**

  The experimental set-up made use of laser light sheet imaging techniques applied to the flame of a propane burner for recording the spatial distribution of unburned propane of HC and OH radicals and soot. Interferograms were recorded using MachZehnder Interferometer configuration with a camera. Shearing interferometry allowed the determination of the gradient of the wave-front deformation a light wave exhibits when passing through a phase object. The interferograms with varying refractive index gradients were analysed using Fourier Transforms.

GENERAL DISCUSSIONS

Taking into consideration expectations expressed in speeches delivered during the Opening Session, the lectures and presentations made at the workshop, general discussions were carried out to chart the way forward.

The discussions were carried out within the undermentioned framework:

i. **OVERALL OBJECTIVE**

To forge and sustain linkages between Universities Research Institutions and Industries for laser and optical application in combustion and environment-related issues.

ii. **STRATEGIES**

a. Thematic planning

- themes or subject areas for which laser and optical techniques

- offer unique advantages
- has proven field record, and
- is cost effective.

b. Working groups on Laser Applications, Combustion, and Environment (LACE Working Group)

c. Capacity Building

- training and development of local expertise (which areas, who?)
- supplementary equipment for LAFOC

d. Climate Change Convention

e. National/Sub-Regional/Regional Projects

- definition of core project areas, and supplementary areas.

With this framework in view, the participants were divided into three sub-groups for further discussions aimed at coming out with concrete recommendations for following activities and programs in the areas of combustion and environment.

GROUP 1

EXPECTED OUTPUTS

1. **PROJECTS**

- applied research projects
- pure research projects
- suggested project areas
  - measurement of greenhouse gases using tunable diode lasers
  - computer modeling of combustion, and emissions (pollutant dispersal)
- a project fund for servicing common or joint projects must be provided by Government and Industry.

2. **CAPACITY BUILDING**

- scientists, engineers, students
- attention to be paid to training of technicians to facilitate maintenance

and improvisation

- fellowships, attachments, postgraduate courses
- provision of Nd-YAG dye tunable laser to LAFOC since it is a versatile tool for combustion and environmental analysis
- acquisition of a mobile laser-based remote sensing facility to be used for environmental monitoring within the sub-region.

GROUP 2

The suggestions from this group focused on combustion-related issues:

1. **Applied Research**
   - identify industrial problems and needs
   - involve engineers and scientists
   - analyse combustion processes of industry and local households
2. **Focus Areas**
   - Burner design (gas burners, spray and droplet combustors)
   - Performance Evaluation/Improvement (process variables)
   - Emissions (chemistry, monitoring, mass balance calculables)
3. **Specific Needs/Problems**

   TOR - smokeless combustion, O_2 monitoring

   VALCO - hydrogen in molten metals, emissions.

GROUP 3

Discussions of this group can be summarised as follows:

1. **PROJECTS**
   - to be discussed and designed jointly with stakeholders
   - should involve the use of simple/basic laser-based equipment
   - project implementation should be coordinated from the stakeholder

institution with already existing basic facilities and trained manpower for implementation at minimum cost and maximum impact.

2. **MANPOWER TRAINING**

- to be balanced between academic and industry.

LABORATORY SESSIONS

The suggestions and recommendations from the three sub-groups were synthesized to produce the Workshop Resolutions.

GROUP 1

1. Mr. Brahima Coulibaly
2. Mr. Baah Sefe-Ntiri
3. Mr. Jumpah Dyson Teye
4. Mr. Ahadzi Gershon Mawutor
5. Mr. James Annan
6. Mr. David A. Ajadi
7. Mr. Diarrassouba Issoufou

GROUP 2

1. Dr. Akeredolu Funso Alaba
2. Mr. Afrane George
3. Mr. Stephen K. Doku
4. Mr. E. K. Asamoah
5. Mr. Ebenezer Kofi Avotri
6. Mr. Mr. Beneditte A. Addo
7. Mr. S. Bamford

GROUP 3

1. Ms Florence Agyei N.A.
2. Mr. Paul Wonkyi
3. Dr. Ismail Mekkaoiu Aloui
4. Dr. Kwaw Anaman
5. Mr. Kakane Victor C. K.
6. Dr. Esther Ugoji

GROUP 4

1. Dr. Matheiu Assa Achy
2. Ms. Catherine Asante-Poku
3. Mr. K. K. Ditsa
4. Mr. William K. Zanoo
5. Mr. Addotey Ivan Andrew Kofi
6. M.EISA Mohammed Eltayeb
7. Mr. Karemera Marembo

	Group 1	Group 2	Group 3	Group 4
Tuesday	1	2:4	3	4
Wednesday	2	3	4:1	1:2
Friday	4:3	1	2	3

Experiment 1 - Mach-Zehnder Interferometer of flame

Experiment 2 - LDV

Experiment 3 - Soot volume fraction determination by absorption

Experiment 4 - Diode Laser Spectroscopy of Rubidium

INTERNATIONAL AND LOCAL LINKS

The workshop on Combustion Diagnostics and Optical Techniques held in Cape Coast, Ghana from 5 - 10 July, 1999 has exposed both engineers and scientists to the use of Lasers to solve some combustion problems. Through the effort of ICS-UNIDO in initiating the organisation of this training course in combustion systems and use of possible optical techniques for measurement, industries, the academia and research institutions have seen the potentialities of Lasers in Combustion diagnostics.

Many Africans at this workshop expressed their desire to use the facilities at Laser and Fibre Optics Centre (LAFOC) to enable them acquire the skills required in this new field. The Laser and Fibre Optics Centre (LAFOC), on the other hand, has established contacts with some industries and institutions in Ghana with the aim of establishing scientific collaboration. All the lecturers at the workshop indicated their willingness to help initiate certain projects such as the Mobile Van monitoring. Greater awareness has also been created and projects have been designed to research into some of the local problems. The Ministry of Environment, Science and Technology and Ministry of Mines and Energy have promised to assist in combustion related research. Istituto Nazionale di Ottica, Firenze, Italy, Centre National de la Reserche Scientifique, Paris, France, and CNR-TeMPE, Milan, Italy and ICS-UNIDO are supporting foreign institutions that are prepared to be involved in these projects. The institutions are prepared to support staff training from African Countries to strengthen activities in the optical techniques in combustion process research. It is expected that such contacts made would help collaborative research work to materialise. In addition, it is hoped that young scientists would acquire skills in the Laser diagnostics in combustion by being involved in projects designed to solve some of the problems pertinent to the industries.

EVALUATION QUESTIONNAIRE

COMBUSTION DIAGNOSTICS AND OPTICAL TECHNIQUES

ORGANISATION

Participants were highly impressed about the publicity, announcement and pre-workshop information process. They found the scientific programme, practicals and the lectures very useful and well presented by the lecturers. The case studies provided by the Oil Refinery, the mining sector and other industries including the Environmental Protection Agency in Ghana about the combustion processes and monitoring technique were very informative. The questions and answer (discussion) sessions were very lively. The participants also found the visit to some industries (Tema Oil Refinery and the Valco Aluminium Smelting Plant) very useful.

However the participants were of the view that a much smaller working group than was used, would have made the laboratory (practical) sections more interesting and beneficial.

DURATION OF PROGRAMME

Most participants thought the number of days used for the workshop was right. However a good number of them were of the view that the programme of activities for the days were too loaded. This did not offer them enough time to interact with the lecturer and other participants from different countries.

TRAINING FACILITIES AND HOTEL

The general consensus was that the hotel accommodation, meals, refreshments and lecture/training rooms were excellent.

ORGANISER'S RESPONSE TO PARTICIPANTS NEEDS

The participants gave the organisers high marks and commended them for the efficient and able manner they addressed their needs and problems any time such problems did arise.

OVERALL PROGRAMME ORGANISATION

The overall impression was that the workshop was excellently organised.
The participants were satisfied with almost everything that went on at the workshop.
Most participants said they were ready to recommend to other scientist from their country and institution to attend similar activity in the future.

While the participants enjoyed almost all the activities, about 80% said they found the practical sessions and the case study provided by the local industries in Ghana, most useful.

Most participants said they gained a lot from the practical sessions. However some thought smaller working groups for the practical sessions would have been preferred.

The visit to some industries in Ghana was most appreciated by the participants.

Participants generally agreed that the workshop was very beneficial. They said the workshop offered them the opportunity to acquire more than basic knowledge in Laser Techniques and its application. It also helped to enlighten them on combustion processes and hazards and how to detect and minimize the effects of these pollutants. A better understanding of combustion systems and laser and optical diagnostics technique were gained.

They expressed the desire to disseminate the information and knowledge acquired during the workshop to their colleagues, students and government officials through seminars and lectures. Some were so motivated that they said they were going to prepare a Comprehensive Report about the worship to their Government so as to help them research into some of the combustion problems in their countries. Others also expressed the hope to build basic optical monitors for monitoring certain emissions in their country.

The participants also suggested a number of programmes and future activities ICS could pursue to help with the technological and scientific advancement in some of their countries. Among these were workshop on

- Fibre Optics and Communication
- Meteorology and climate change
- Electronics and Data Processing

EVALUATION OF LECTURERS AND SPEAKERS

According to the participants the lecturers and speakers, both resident (local) and international, were excellent. The presentations were well delivered. Course materials were also excellent. Questions were well handled by the lecturers. The questions and answers (discussion) sessions were very lively.

COMMENTS

The workshop was very useful for it did open the way for more interactions between research institutions and the industries.

SUMMARY AND STATISTICS OF THE EVALUATION

ORGANIZATION

	EXCELLENT	V. GOOD	GOOD	FAIR
INFORMATION PROCESS	6	8	3	0
ANNOUNCEMENT AND PRE-COURSE MATERIAL	3	10	2	0
ORGANIZER'S RESPONSE TO PARTICIPANT NEEDS	8	7	3	0
OVERALL PROGRAMME ORGANIZATION	7	9	3	0

SCIENTIFIC PROGRAMME

	EXCELLENT	V. GOOD	GOOD	FAIR
SCIENTIFIC PROGRAMME	9	7	2	0
APPLIED LECTURES	6	10	1	0
USE OF SMALL WORK GROUP	1	5	8	2
CASE STUDY	3	6	6	0
TIME SPENT BY LECTURERS IN CLASS	2	12	3	0

DURATION OF WORKSHOP

	JUST RIGHT	TOO LONG	TOO SHORT
NO. OF DAYS	14	0	4
LENGTH OF DAYS	13	5	0

FACILITIES

	EXCELLENT	V. GOOD	GOOD	FAIR
LECTURE/TRAINING ROOM	9	10	1	0
BREAKS/REFRESHMENTS	10	6	3	0
HOTEL ACCOMMODATION	12	7	0	0
MEALS	4	10	5	0

EVALUATION OF LECTURES/SPEAKERS

	EXCELLENT	V. GOOD	GOOD	FAIR
COURSE MATERIALS	7	10	1	1
RESIDENT LECTURERS PRESENTATION	4	15	1	0
INTERNATIONAL	6	10	1	0
ABILITY OF LECTURERS TO ANSWER SPECIFIC QUESTIONS	7	9	2	0

WOULD YOU RECOMMEND TO OTHERS FROM YOUR INSTITUTION/COUNTRY TO ATTEND SIMILAR ACTIVITY IN THE FUTURE

YES - 19

MAYBE - 0

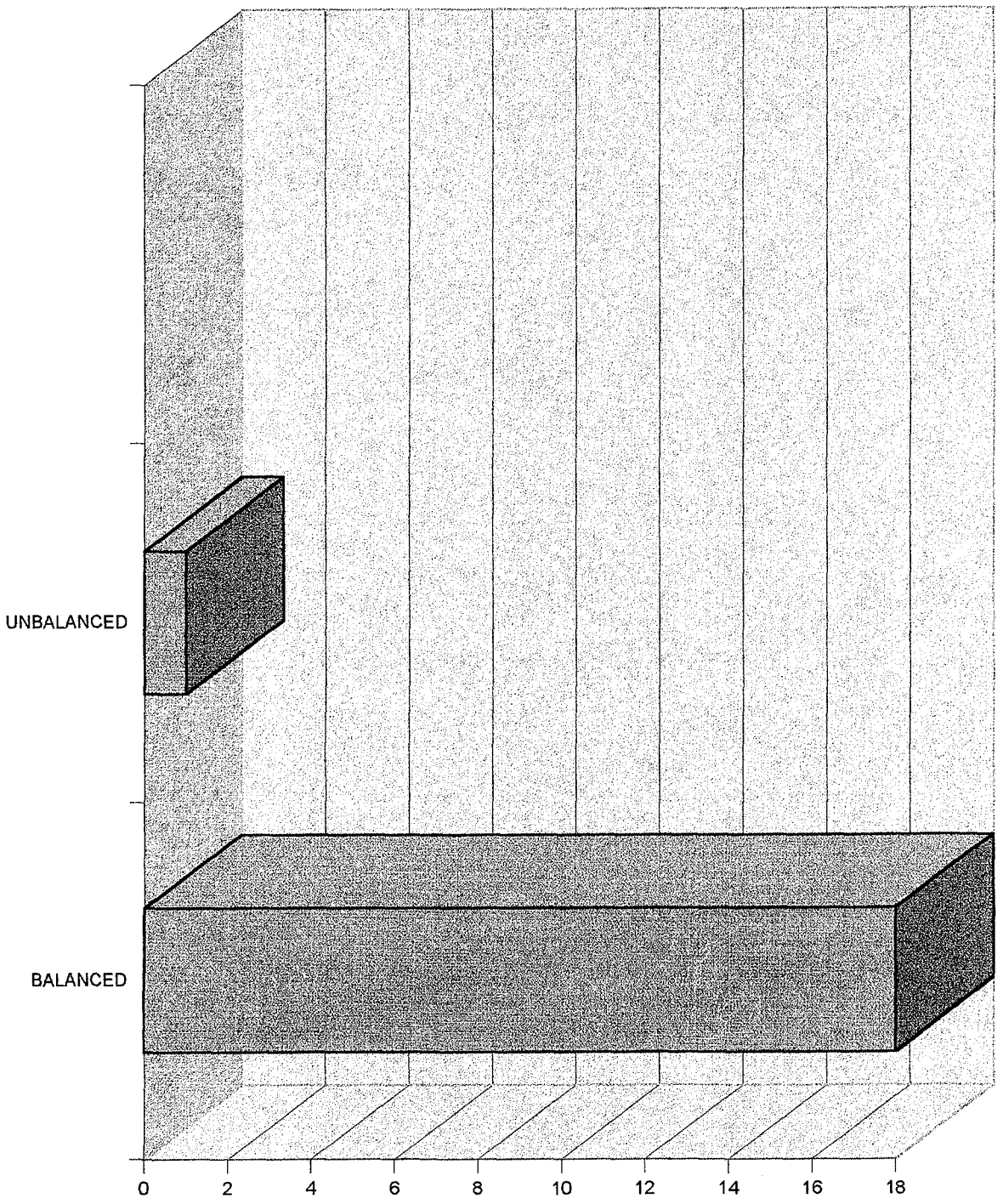
NO - 0

STUDENT SCIENTIFIC KNOWLEDGE

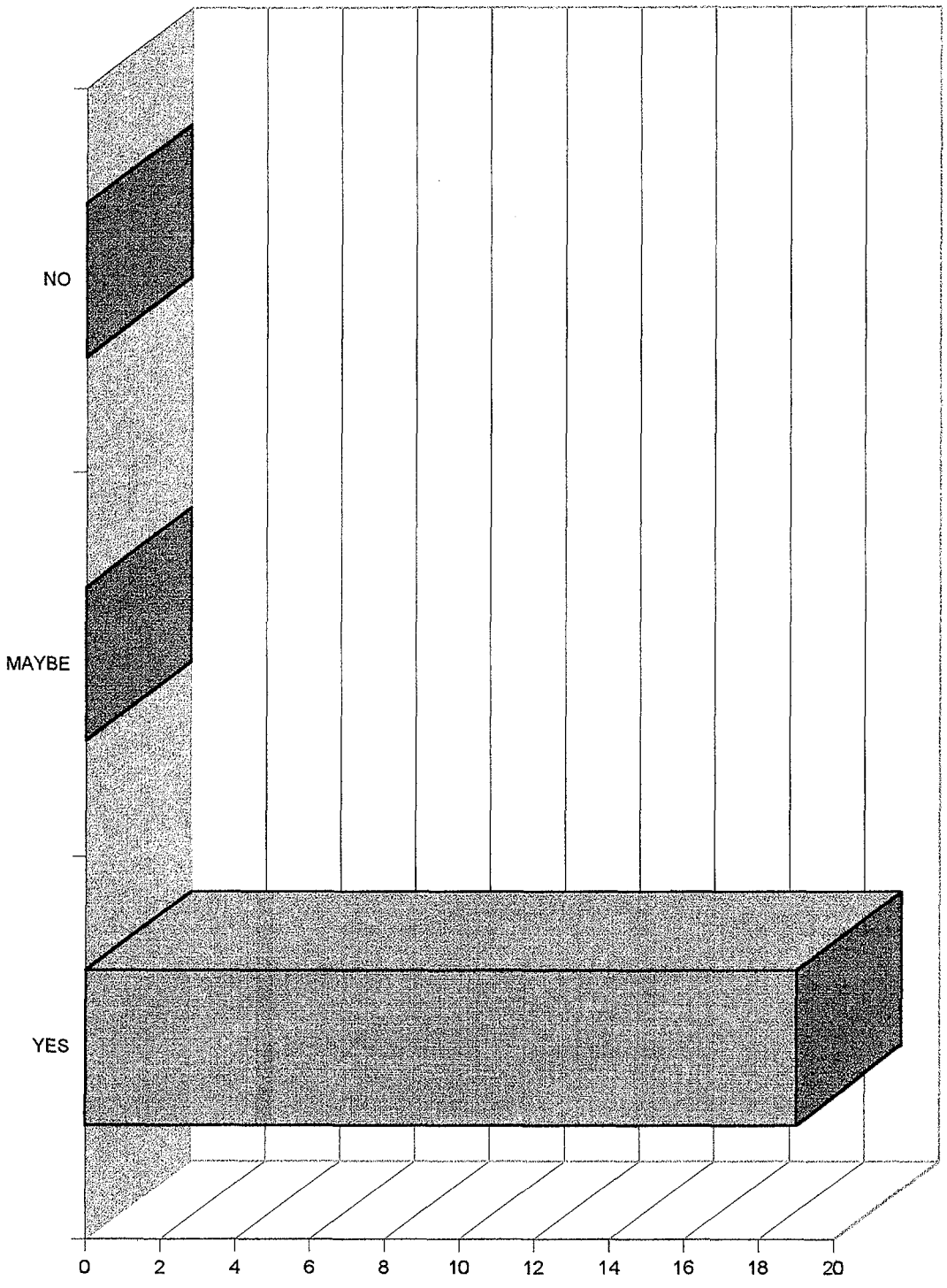
BALANCED - 18

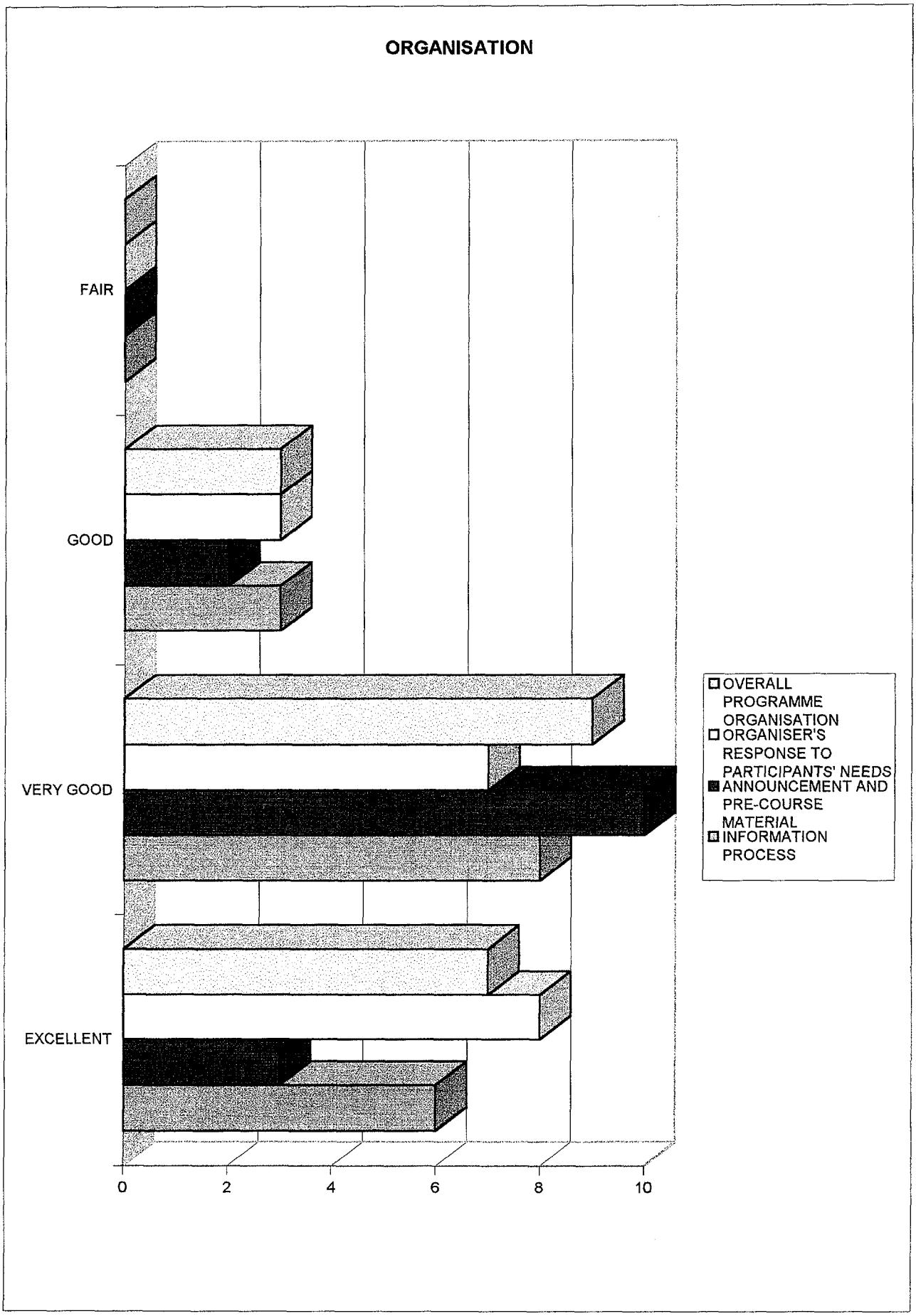
UNBALANCED - 1

STUDENT SCIENTIFIC KNOWLEDGE



WOULD YOU RECOMMEND TO OTHERS FROM YOUR INSTITUTION/COUNTRY TO ATTEND SIMILAR ACTIVITY IN THE FUTURE?




ORGANISATION
FAIR
GOOD
VERY GOOD
EXCELLENT
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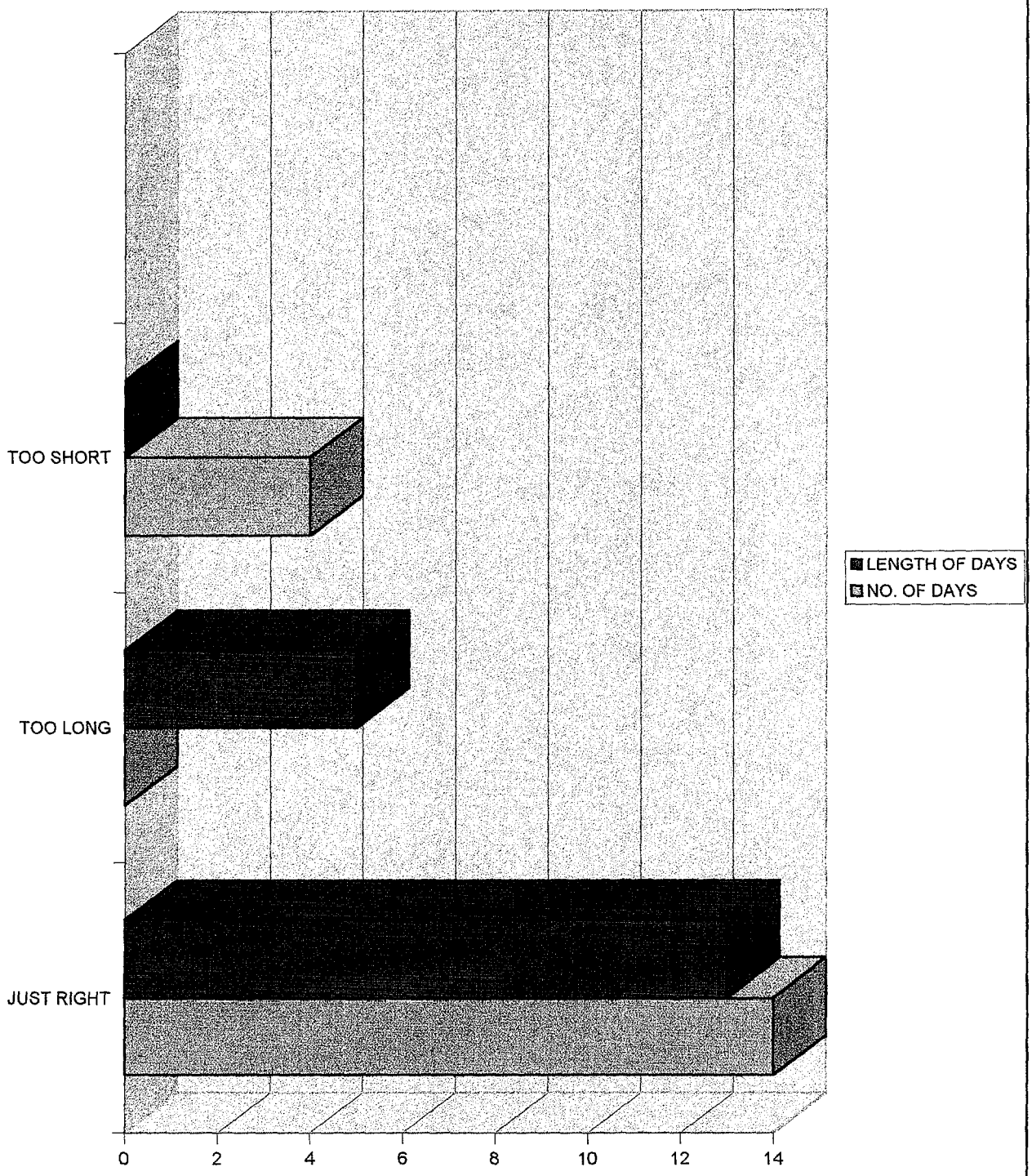
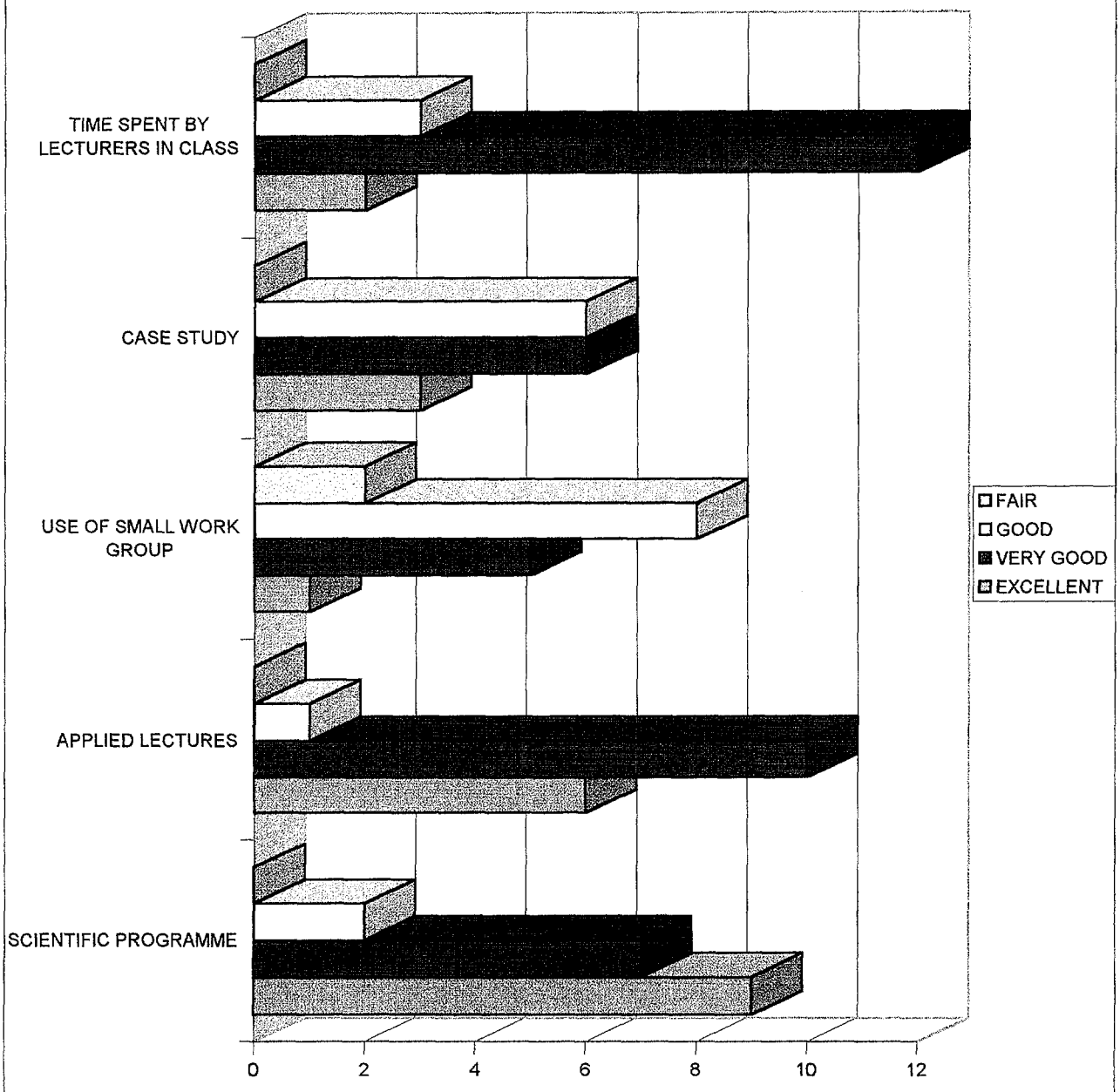
OVERALL PROGRAMME ORGANISATION
ORGANISER'S RESPONSE TO PARTICIPANTS' NEEDS
ANNOUNCEMENT AND PRE-COURSE MATERIAL
INFORMATION PROCESS

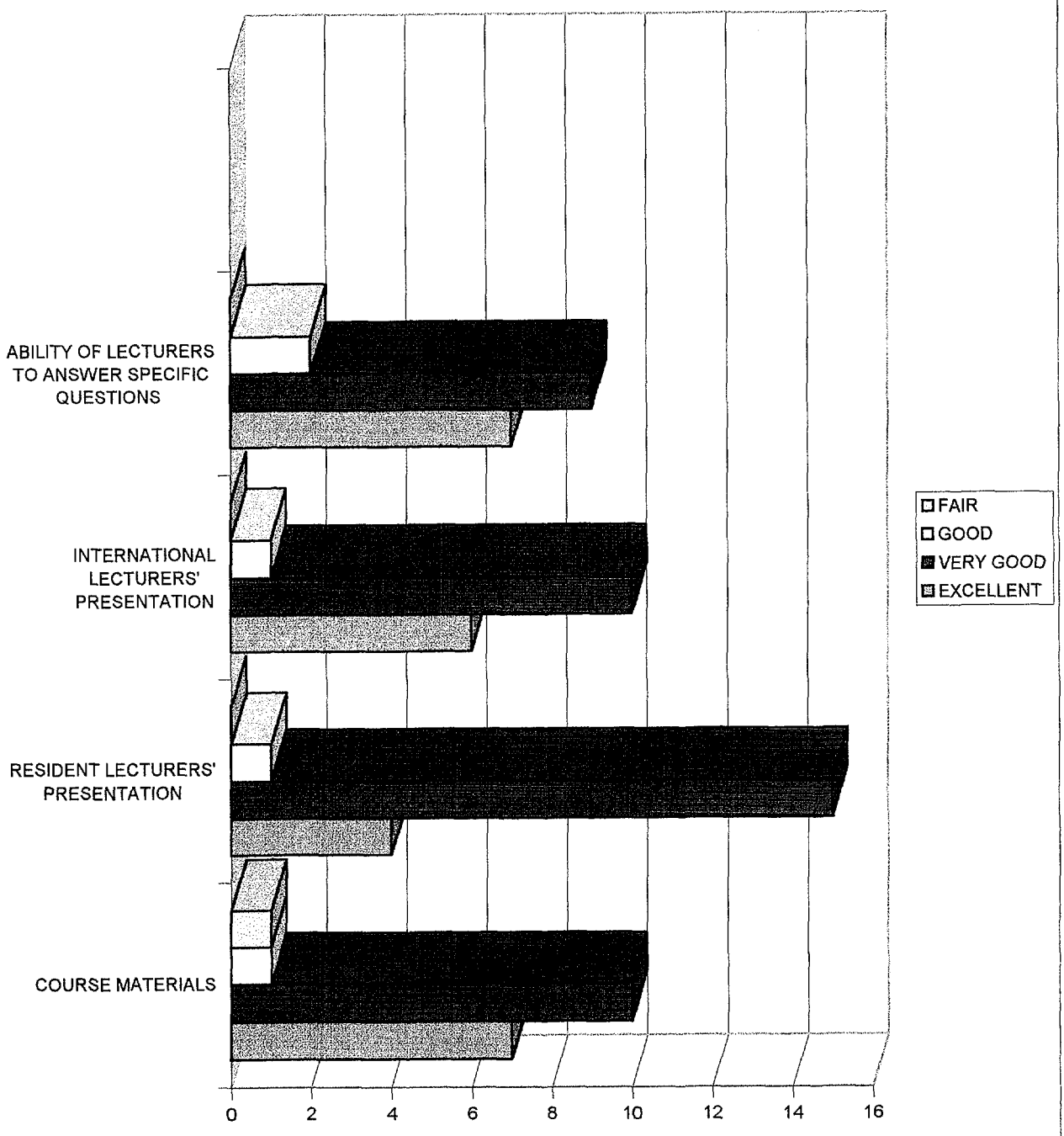
DURATION OF WORKSHOP



SCIENTIFIC PROGRAMME



EVALUATION OF LECTURERS/SPEAKERS



CONCLUSION AND RECOMMENDATIONS

MAIN ACHIEVEMENTS

In the presentations by top level experts in combustion and exposure of participants to laboratory work, the following problems were identified as:

1. Most industries, though are contributors to gas emissions, did not have adequate equipment to monitor such emissions.

2. No elaborate data are available to guide policy makers in coming out with guidelines for the limitation of pollutants.

3. The sub-region in Africa lack monitoring units and as such require mobile LIDAR station using DIAL to make pollution measurements in order to bring awareness to the actual pollution levels.

4. The need of optimisation of combustors by initiating retrofit of all combustors of existing factories.

5. The existence of the pollutants are affecting a climactic change.

6. The initiation of close collaboration between industries, research institutions and the universities by ICS-UNIDO.

7. The need to quantify combustion emission levels.

8. Create a general awareness of the effects of combustion processes on the environment through training courses.

9. To train Scientists and Engineers in combustion systems through post-graduate work with much sponsorship from the industries.

10. To initiate thematic group to oversee collaborative work in combustion research out of the case studies presented by the mines and industries.

11. Identifying projects through some existing problems that result from combustion process.

12. Improvement of oil lamps and kerosene stoves to limit PAH and soot emissions or shift to alternative source of energy which is environmental friendly.

13. The need to strengthen the monitoring techniques of vehicular movement with close collaboration with the EPA.

14. To establish Laser-based optical systems to monitor industrial activities.

15. To link up international collaboration of the lecturers and institutions to foster staff training.

16. The need to develop experiments mounted at the course into projects of user - oriented that can present immediate benefits for the public.

17. The need to come out with some modalities to regulate pollution from combustion systems by looking at design parameters of combustors and use of biomass at the rural areas.

18. The transfer of technical know-how to participants. The need to encourage industries to interact with research institutions and universities for effective R and D to improve on their products.

Participants realised that the Laser based diagnostics methods are essential in the combustion systems and there was the need to acquire equipment to do effective monitoring in the sub-region. In order to promote the awareness of the combustion process, there was the need to organise short courses as well as training programmes that would strengthen the collaborative work. Participants appreciated the way the workshop was organised and the role the industries and mines played. The facilities both at the laboratory and the hotel were excellent. Their visit to industries which was organised during the workshop improved their understanding of most combustion processes and came face to face with some of the practical problems in combustion on the field.

Participants found the training very useful because:

a. Lecture notes were made available

b. Lectures were well delivered

c. Contributed Papers fell within their expectations

d. Case studies were well outlined to explain most practical problems on the field

The detail for the subject covered are summarized in this report which cover from modeling to monitoring techniques in combustion systems.

Statistics show that twenty-two {22} University Lecturers, ten {10} Research Scientists, and Environmentalists, ten {10} Scientists and Engineers from Industries, two {2} Engineers from the Mines and twenty {20} undergraduate and graduate students and sixteen {16} people from the National Organising Committee attended the workshop. In all eighty {80} people were present at the workshop. Such encouragement given to most participants made the workshop, very lively and interesting. The Lecturers were quite helpful and mixed up with the participants.

Participants found the practical sessions useful but could not have enough hands-on opportunity with the equipment due to the group size. In all the workshop was successful and everyone played a very useful role. We attach herewith the pictorial statistical presentation of the evaluation of Lecturers and participants in pages 26-31.

RECOMMENDATIONS

Participants really appreciated the need to combine Lectures with practice and suggested that smaller groups of two or three people should be encouraged to enable them have enough hands-on experience.

Organisations that sell Laser equipment for combustion systems, and optical components need to be encouraged as well as vendors of software packages for modeling need to be invited to make exhibits or give some lectures.

Since this activity is first of its kind in the Sub-Saharan Africa, participants were of the opinion that it should be a regular feature in the region.

The group discussions made some recommendations for a team work in monitoring for the sub-region and to make available obtained data on emissions for governmental use. The Laser and Fibre Optics Centre should be strengthened to organise short courses and to implement activities on the projects that have been designed for ICS-UNIDO consideration. The Lecturers involved in this activity should be encouraged to give their expertise to LAFOC in the training of students and Engineers on the post-graduate programme level.

This document is annexed with the following:

i. Poster
ii. Folder
iii. Programme, Abstracts and Laboratory manual
iv. Application forms of the participants
v. Evaluation Questionnaire
vi. Material distributed as Lecturers' notes.

1-9-99
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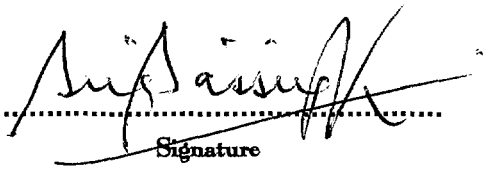
Date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Signature
Dr. P.K. Buah-Bassuah
Local Organiser

RESOLUTIONS ADOPTED BY THE PARTICIPANTS AT THE INTERNATIONAL WORKSHOP ON COMBUSTION DIAGNOSTICS AND OPTICAL TECHNIQUES CAPE COAST, GHANA 5TH-10TH JULY, 1999

INTRODUCTION

We, the participants of the above workshop having deliberated (through lectures, laboratory sessions, and industrial visits) on various topics such as Combustion Diagnostics, Optical Measurement Methods, Absorption and Emission Spectrometry. Laser Probing of Combustion, and Air Pollution due to Combustion, have realised the tremendous potential Laser and Optical Techniques (LOT) offer in industrial applications for combustion - and environment-related issues.

WE also appreciate the support of the International Centre for Science and High Technology (ICS - UNIDO, Italy), Tema Oil Refinery (TOR) and other companies in the petroleum-related sector (Ghana).

ISSUES IDENTIFIED

We have noted with serious concern that:

1. Research and development in combustion systems, locally and within the African Region, is scanty and uncoordinated.

2. Combustion processes, both industrial and domestic, lead to the emission of pollutants into the atmosphere

3. The advantages that laser and optical techniques offer as a tool in combustion and environmental diagnosis is woefully under-utilised by our industries

4. There exists a lack of adequately trained manpower, and insufficient facilities within the public and private sector for atmospheric pollution studies.

RESOLUTIONS

Taking cognisance of the above-mentioned concerns, and bearing in mind our objective to forge and sustain linkages between Universities, Research Institutions and Industry for laser and optical applications in combustion - and environment related issues, we the participants at this workshop hereby resolve as follows:

1. Applied research projects should be developed based on need-driven projects identified, designed, planned, and implemented jointly with industry and relevant sector Ministries.

2. Projects must focus on enhancing understanding of combustion processes and atmospheric pollutant dispersal through experiments, simulation and modeling.

3. Thematic plans to be developed should include the following key issue areas:

   Burner design, performance, evaluation and improvement of combustion process, atmospheric emissions and measurement of greenhouse gases.

4. Scientists, Engineers, Technicians and Students should be trained and developed for the establishment of local expertise in combustion, emission control and laser and optical techniques.

5. Supplementary equipment and facilities should be provided to the laser and Fibre Optics Centre (LAFOC) to facilitate the implementation of identified joint projects.

6. An Oversight Committee should be set up to serve as a co-ordinating body for national and international stakeholder institutions, to plan follow-up activities and to seek for funding for projects and programmes, and explore opportunities for regional cooperation.

7. Analysis and evaluation of alternative transportation methods to reduce air quality emission should be undertaken.

PROJECT TOPICS

The following project topics were fashioned out of the lectures and case studies presented by the lecturers and the participating institutions.

DEVELOPMENT OF DISPOSABLE LOCAL ADSORBENTS FOR THE REDUCTION OF AUTOMOBILE POLLUTANT EMISSIONS

BACKGROUND

Most of the vehicles imported into Ghana are so old that even if they have one, the non-regenerable synthetic adsorbents fitted to their exhaust by the original manufacturers have long outlived their usefulness. Vehicular emissions have therefore become the fastest-growing source of the oxides of carbon, sulphur and nitrogen, and unburnt hydrocarbons building up in the atmosphere of developing countries like Ghana.

OBJECTIVE AND USES

It is proposed to develop a local adsorbent which is cheap, reasonably effective, lightweight and disposable. The adsorbent will be packed into containers similar to the muffler attached to car exhaust lines. The unit can be removed periodically, after the adsorbent is spent, and the adsorbent replaced. It is hoped that some use will be found for the spend adsorbent, perhaps in the building industry, so as not to merely transfer the pollution problem from one area to another.

METHODOLOGY AND RESULTS

It is known that coconut husks, after appropriate treatment, is a good adsorbent. The work will involve the determination of the adsorbent properties of the coconut fiber, after undergoing different conditions of treatment. Following the preliminary laboratory work, the adsorbent will be tried directly on the exhaust of an internal combustion engine and the levels of emissions measured over time, using appropriate equipment.

Suggested by: **George Afrane, KNUST**

Dyson T. Jumpah, EPA

P.K. Buah-Bassuah, LAFOC

REDUCTION OF HAZARDOUS EMISSIONS FROM OIL AND BIOMASS BURNING APPLIANCES IN THE GHANAIAN HOUSEHOLD

Goal: The goal of this project is to reduce emissions of Green House Gases {GHG} through efficiency improvements in combustion processes.

Objective: The purpose of the project is to improve the combustion efficiency of biomass and oil burning stoves and lamps thereby reducing operating costs as well as unhealthy emissions.

The specific objectives are as follows:

1. analyse combustion processes in charcoal, fuelwood and kerosene burning stoves through theory. simulation and experimentation

2. analyse combustion processes in kerosene and vegetable oil burning lamps through theory, simulations and experimentation.

Implementation Strategy

The project should be implemented by an interdisciplinary team from industry, university and research institutes. The disciplines should include social scientists, scientists and engineers.

Funding

It is essential that industry funding should lead this project. However, all implementing organisations should share in the funding.

International Collaboration

Prof. Mansour - Egypt

Prof. Martin - France

Prof. Mazzinghi - Italy

Prof. Yeboah - USA

Suggested by: **F. O. Akuffo**
KNUST, Kumasi

PROJECT TOPICS

SOOT REDUCTION IN KEROSENE STOVES AND LANTERNS

Objective:

(i) To look for blending qualities between kerosene and alcohol for PAH reduction.

(ii) To use of laser based techniques to measure the emissions from the new blend of fuel.

Method:

The chemical kinetics of the blended fuel and soot determination of the emitted smoke will be studied. He-Ne Laser beam will be passed through the smoke and the scattering effect would be detected. The data will be interfaced to a computer for analysis.

Benefits:

- To serve as a means to increase the life expectancy of women who use such source of fuel and also use such stoves for domestic cooking and also use lanterns in the bedrooms.

- To serve as capacity building for M.Phil. students and to strengthen the research base in combustion.

Participating Group:

- Laser and Fibre Optics Centre
- Department of Mechanical Engineering, KNUST, Kumasi
- Department of Chemical Engineering, KNUST, Kumasi.
- Department of Chemistry, University of Cape Coast.
- ICS - UNIDO
- Centre for Scientific and Industrial Research, CSIR.
- Ghana National Petroleum Corporation, Tema.

Funding:

- Request for equipment from ICS and personnel and use of local funds and expertise for the project to take off.

Suggested by: **Dr. P.K. Buah-Bassuah**

MOBILE VAN FOR POLLUTION MONITORING FROM COMBUSTION PROCESS

Background:

At the round table discussion of the workshop on Combustion Diagnostics and Optical Techniques, it was observed that most of the industrial operations are not backed by regular monitoring of the emitted gases in the whole sub region. It was proposed that if a mobile van with all the facilities could be initiated to take up such project it will be of an economical value.

Objective:

- To monitor pollutants from stacks of industries, power plants and other industrial sites of the sub region.
- To establish the environmental impact of the pollution produced and to advise policy makers.

Methodology:

The use of optical remote sensing techniques such as Differential Absorption Lidar (DIAL) mounted on a vehicle suitable for operation in remote areas. To monitor pollutants such as oxides of Nitrogen, sulphur and carbon and also PAH. To work in close collaboration with the meteorological stations to relate data with time of day weather condition.

Benefits:

- To be used to monitor from site to site and from country to country in the sub region.
- Emergency assessment of pollutants in large cities could be implemented.
- To evaluate risks of pollutants to the population and advise decision makers accordingly.
- Assist Ghanaian, Nigerian and Ivorian industries where flare containing pollutants are released into the atmosphere.

Participants:

- Tema Oil Refinery Limited
- Volta Aluminium Company
- Environmental Protection Agency (EPA)
- Laser and Fibre Optics Centre, University of Cape Coast.
- Centre for Scientific and Industrial Research

- Research Councils in Togo, Cote D'Ivoire and Nigeria
- Meteorological Department of Ghana

Foreign Involvement:

a. Istituto Nazionale di Ottica
b. ICS Laser and Optical Fibre Laboratory, Trieste Italy
c. CNRS Paris, France (Prof. Martin's Outfit)

Equipment: Require a donated vehicle in which are the Laser (DIAL)

Personnel: One technician and two scientists to be trained to do the monitoring.

Results:

Data acquired from this studies would be made available to Governments, UN organisations. The work could be developed into a long term project.Aimed at making it a viable resource centre for monitoring.

Funding:

Oil Companies are prepared to give local funding and logistics on the research when the equipment are acquired.

ICS is being requested to provide vehicle, equipment, funding for training personnel abroad and one expert to work closely with the local personnel.

Suggested by:
Group 1 and Pierre Mazzinghi

PROJECT TOPIC

QUALITY FISH SMOKING IN GHANA

Background:

Ghana exports treated fish (smoked) to the European Union. A lot of these fish are smoked. Feasibility studies is being made to find out the species in the smoke and effect on the fish to obtain a good quality smoked fish. Food Research Institute is making research into constituents of these smoke to enable them determine the nature of smoke which can make good quality smoking.

Objectives:

- To promote quality measures required in fish smoking.
- To evaluate the soot of PAH constituents which affect human health.
- To give alternate new species of fiel for combustion to obtain non-dangerous products in the smoke.
- To study the various items such as sugar cane chaff, wood and other products used for smoking.
- To recommend new sources of energy required for quality fish smoking
- To use laser techniques to measure the observed parameters.

Methodology:

Two sources of energy will be identified such as Gas, biomass and other fuel. Smoke will be made from these species and identify the pollutant species from it including percentage of each pollutant. Laser diagnostics is required to test on the field local fish smokers and compare results to the laboratory.

Benefits:

Information and data would be made available to FAO and other UN organisations.

- Training post graduate students.
- Improving the quality of smoked fish.
- Improving the health of consumers.

Participating Group:

- Laser and Fibre Optics Centre, U.C.C. Ghana
- Food Research Institute of CSIR.
- Dept. of Mechanical Engineering, KNUST, Kumasi

Equipment:

Purchased of few optical components to support the existing ones at LAFOC.

Funding:

Requesting UNIDO and FAO to support such work to enable better combustion techniques to be used.

- Ministry of Food and Agriculture
- Ministry of Environment, Science and Technology
- Centre for Scientific and Industrial Research (CSIR).

Suggested by: Dr. P.K. Buah-Bassuah,
LAFOC

Prof. F.O. Akuffo,
Food Research Institute

PROPOSAL TOPICS

EMISSIONS FROM VEHICULAR MOVEMENTS: IMPACT ON AIR QUALITY

Background:

Most of the vehicular movements in the country release a lot of pollutants to the environment. The air quality in both residential and commercial areas are quite polluted. Environmental Protection Agency of Ghana lacks equipment to monitor the PAH's in the atmosphere.

Objectives:

- To develop a laser based instrument for monitoring polycyclic Aromatic Hydrocarbons (PAH's) in the ambient air and also in the rural areas out of the smoke of their fire.
- To monitor also the NOx, COx in the environment.
- Impact of the data collected on the climate.

Methodology:

Basic research using soot measurement techniques to monitor PAH's using Laser based equipment. Laser absorption technique to be implemented to measure the fractional volume. To detect also the presence of the gases from the vehicles. Sample of busy traffic areas in the cities such as Accra, Abidjan, Kumasi and Takoradi could be made and statistics of the pollutants given.

Participating Group:

- Environmental Protection Agency, Ghana.
- Laser and Fibre Optics Centre
- TeMPE of Milan (Dr. Zizak's Lab)
- CNRS (Dr. Martin's Lab)
- Laser and Optical Fibre Laboratory, Trieste (Dr. Danailov's Lab)
- Vehicle, Licensing and Examination Division (VELD) of Ministry of Roads and Transport.

Benefits:

- Monitor the pollutant levels in the cities along the coast of West Africa such as Ghana, Togo and Cote D'Ivoire.

- To assess the impact of the pollutants on the environment e.g. Accra and Kumasi.

- To use data collected to formulate policies on the use of cars and also car importation.

Funding:

- To request ICS to help with personnel and equipment to initiate the project.

- ICS to help train personnel in some of the European Laboratories.

- Local funding from the oil companies to test the quality of the fuel products and give them feed back.

Results:

The studies will initiate stronger group to monitor pollutants in the environment and help create awareness of the public in the combustion process from the vehicles.

This information was compiled from the case study presented by Mr. D. Jumpah and Mr. Kwaw Anaman.

Compiled and written by:
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INDUSTRIAL MONITORING ACTIVITIES OF TEMA OIL REFINERY, VOLTA ALUMINIUM COMPANY AND TAKORADI THERMAL PLANT

Background:

During the Industrial tour to the Tema Oil Refinery and the Volta Aluminium Company and then the presentation of Takoradi Thermal Plant at the workshop, it was realised that though certain measures have been taken to improve upon plant performance and release of less combustion pollutants little knowledge is known on the level of pollutants to the atmosphere.

Objectives:

Using advanced techniques in combustion diagnostics and emissions monitoring in the quest for improved energy efficiency

- application of conventional as well as advanced techniques for the analysis of combustion processes and monitoring of emissions at TOR, VALCO, and Takoradi Thermal Plant of VRA.

Methodology:

- Use of LAFOC facilities and expertise to set up basic experiments to monitor the flame combustion for image diagnostics.
- To check on line monitoring of fuel/air ratio for the production of flame in TOR, VALCO and VRA.
- To work in close collaboration with engineers at the factory to ensure the emission of less pollutants.
- To initiate postgraduate training in combustion process using the facilities at the industries and LAFOC. To strengthen the combustion Laboratory at Kwame Nkrumah University of Science & Technology as well.

Equipment:

- Request for a Laser commercial/industrial monitors and set up of some experimental configuration for the project.

Participants:

- Tema Oil Refinery
- VALCO
- VRA
- LAFOC
- ICS-UNIDO
- Department of Mechanical Engineering, Kwame Nkrumah University of Science & Technology, Kumasi.

Funding:

- The local industries stated above to fund it.
  Request for equipment from ICS-UNIDO.

Benefits:

- To develop capacity in Ghana with respect to combustion process analysis and emission monitoring using laser techniques.
- To prevent excessive emission of pollutants.
- Exchange of staff among academia and industry.

Drafted by:
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Dr. Paul K. Buah-Bassuah,
LAFOC,
Cape Coast.

A SECOND TRAINING COURSE IN COMBUSTION PROCESS IN GHANA

Preamble:

Based on the recommendation of participants at the workshop on Combustion Diagnostics and Optical Techniques in Cape Coast from 5 - 10 July, 1999, Scientists and Engineers were of the view that in follow-up training programme should be made and to create awareness to the people in the sub-region and encourage more industrial participation using the facilities at LAFOC. We need to focus also on one of the areas in the first Workshop (eg. combustion emissions and pollution).

Topic:

Combustion Processes for Industrial Development

Beneficiaries:

Young Scientists, engineers, environmentalists from research institutes, Universities, industries and Government agencies. Participants from similar institutions in Africa.

Objectives:

- To provide the know-how and laboratory facilities to projects initiated from the last workshop.
- To enhance training programme at LAFOC and ensure M.Phil projects in this field.
- To encourage more industrial participation in combustion problems
- To promote good relationships and rapport between industry and research institutions
- To use the DIAL system to educate people about the emissions in the environment.

Duration and Proposed date:

7 days in July, 2002.

Organisers:

- Laser and Fibre Optics Centre, University of Cape Coast
- School of Engineering, KNUST, Kumasi
- Centre for Scientific and Industrial Research (CSIR), Accra.

Sponsors:

- International Support: ICS and UNIDO

Local:

- Tema Oil Refinery
- Volta River Authority
- University of Cape Coast
- Kwame Nkrumah University of Science and Technology
- Shell Ghana Limited.

All the project topics were suggested and prepared by the following Engineers and Scientists.

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Dr. Abeeku Brew-Hammond, Department of Mechanical Engineering, Kumasi

Mr. Dyson Jumpah, EPA, Accra

Dr. P. K. Buah-Bassuah, LAFOC, UCC, CApe Coast

Information was derived from the speeches of the Invited Dignitaries, contributed papers of participants and case studies form industries.

By: Dr. P.K. Buah-Basuah
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PROGRAMME FOR THE ICS INTERNATIONAL WORKSHOP ON "COMBUSTION DIAGNOSTICS AND OPTICAL TECHNIQUES" {5-10TH JULY, 1999}

Time	SUNDAY {04-07-99}	MONDAY {05-07-99}	TUESDAY 06-07-99	WEDNESDAY {07-07-99}	THURSDAY {08-07-99}	FRIDAY {09-07-99}	SATURDAY {10-07-99}
8.00-9.00		Registration		Introduction to turbulent combustion **Dr. D. Veynante**	Excursion to Tema and a visit to Tema Oil Refinery (TOR) and Volta Aluminium Company (VALCO)	Round Table Conference {Resolution} **Dr. P. K. Buah-Bassuah**	*Combustion processes of diesel engines in manganese mining activities* **Prof. Yaw Yeboah**
09.00-10.00	Visit to Kakum Forest	Opening Ceremony	Applications of Laser Diagnostics in Flames and Engines **Prof. P. Ewart**			Turbulent combustion Modeling: Classical Reynolds Averaging Approaches - Large Eddy Simulations - **Dr. Veynante**	Particle image velocimetry of Premixed methane - air flames **Prof. Yaw D. Yeboah**
10.11-11.00			*Optical Diagnostics of Air Pollutants* **Prof. P. Mazzinghi**	Monitoring Air pollutants *in combustion* **Dr. PK Buah-Bassuah**		i. Improvement of the modeling industrial furnaces and processes following experimental observations. ii. Analysis of domestic gas appliances for hot water production by laser induced fluorescence and fourier transform emission spectroscopy measurement. **Prof. J.P. Martin**	Aethalometer applications for real monitoring of combustion derived aerosol carbon **Dr. F. A. Akeredolu**
11.00-11.30		C O F F E E B R E A K					
11.30-12.30		Visit to the Laser and Fibre Optics Centre by *Dignitaries and Invited Guests.*	Advanced Measuring Techniques in flames; Flow Field and Temperature Measurements **Prof. M. Mansour**	Needs for optical measurements in combustion process for energy efficiency improvement and pollution abatements **Prof.J. P. Martin**			Pollutants from Combustion **E. K. Avotri**
12.30-14.00		L U N C H				Combustion processes in Oil Refinery **Ing. K. K. Ditsa, TOR**	
14.00-15.00	Visit to Elmina Castle	Combustion Process, What is it? **Prof. F. Akuffo**	Combustion Modeling **Dr. Brew-Hammond**	Advanced Measuring techniques in flames; major and minor species concentration *measurements* **Prof. M. Mansour**		CO2 - TEA Laser-based *lidar dial system* for the detection of hydrocarbon pollution in the atmosphere. **Dr. Taieb Gasmi**	Combustion processes monitoring by the Environmental Protection Agency **Mr. Dyson T. Jumpah**
15.00-15.30		Principles of Laser Diagnostics for *Combustion.* **Prof. P. Ewart**	C O F F E E B R E A K				Laser doppler velocimetry and high speed video imaging for combustion and emission control research **Prof. Yaw D. Yeboah**
15.30-18.30		Coffee Break	Laboratory Session II	Laboratory Session II		LUNCH	
		Monitoring air pollutants with spectroscopic techniques **Prof. P. Mazzinghi**				Combustion processes in thermal plant and energy generation: **Ing. Stephen Doku**	Case Study: Pollution from motor vehicles in Ghana **Mr. Kwaw Anaman**
20.00		Reception	Conference Dinner	Supper and Entertainment	Dinner	A Case Study - Group Discussion	**Closing Ceremony** **Lunch - Departure**