Popular Summary of the Test Reports on Biogas Stoves and Lamps prepared by testing institutes in China, India and the Netherlands

Biogas burning

Biogas light

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Abbreviation

BIS	Bureau of Indian Standards (BIS), Manak Bhavan, New Delhi, India
CH_4	Methane gas
CO	Carbon monoxide gas
CO_2	Carbon dioxide gas
dia.	Diameter
CEEIC	Chengdu Energy-Environment International Cooperation, Chengdu, People's Republic of China
DRES	Department of Renewable Energy Sources, College of Technology and Engineering, M.P. University of Agriculture and Technology, Udaipur, Rajasthan, India
GASTEC	Kiwa Gastec Certification P.O. Box 137, 7300 AC Apeldoorn Wimlmersdorf 50, 7327 AC Apeldoorn, The Netherlands
H_2O	Water
H_2S	Hydrogen sulfide gas
NSDBS	National Standard of the People's Republic of China on Domestic Biogas Stove: GB/T 3606-2001. State General Administration of Quality Supervision and Inspection and Quarantine of the People's of Republic of China (AQSIQ), No.9, Madian Donglu Haidian, district Beijing, 100088, People's Republic of China
O_2	Oxygen gas
SNV	Netherlands Development Organisation
STP	Standard Temperature (0 ^oC or 273 ^oK) and Pressure (760 mm of mercury)
WG	Water Gauge

Unit of measurements and conversion factors

Unit

atm	Atmosphere (Unit of pressure; 760 mm mercury)
^oC	Temperature in degree Celsius
cm	Centimetre
cm^2	Square centimetre
dB	Decibel
hr	Hour
J	Joule
l	Litre
lm	Lumen
lx	Lux
k	Kilo (10^3)
^oK	Temperature in degree Kelvin
kcal	Kilocalories
kg	Kilogram
kW	Kilowatt
kWh	Kilowatt per hour
m	Metre
m^2	Square metre
m^3	Cubic metre
min	Minute
mm	Millimeter
MJ	Mega Joules
N_2	Nitrogen gas
N/m^2	Newton per cubic metre (Unit of pressure)
ppm	Parts per million
sec	Second
Pa	Pascal (Unit of pressure)
v/v	Volume by volume
W	Watt

Conversion factor

Unit of Pressure: 1 Pa = N/m^2 and 1000 Pa = 1 $kN//m^2$

Unit of Work, Energy and Power: 1 kWh = 3.6 $x10^6$ J= 860 kcal

Unit of Temperature: 0 ^0C = 273 ^0K

Terminology

Air regulator: A device such as shutter, screw, clip, vane used for regulating the amount of air entrained by a jet of gas.

Burn back: It is a movement of flame from the combustion chamber back along the incoming fuel stream.

Burner: A device that positions a flame in the desired location by delivering gas and air to the location so that controlled, continuous combustion is achieve

Burner head: the part of a burner that incorporates the burner ports.

Calorific value: It represents the energy content of a fuel, expressed in units, such as kilocalorie or Joule.

Combustion efficiency: It is the efficiency of converting available chemical energy in the fuel to heat. Efficiencies of conversion to usable heat are much lower.

Combustion stability: Under the rated pressure, combustion is stable when the burner flame is uniform, stable and free of burn, flame-lift or yellow flame or soot.

Complete combustion: It takes place when all carbon and hydrogen in the fuel have been thoroughly reacted with oxygen, producing carbon dioxide and water vapor.

Excess air: The amount of combustion air supplied to the fire that exceeds the theoretical air requirement to give complete combustion. It is expressed as a percentage.

Flame blow-off: Separation of a flame from burner port resulting in extinction.

Flame lift: Separation of a flame from burner ports, whilst continuing to burn with its some distance from the port. Excessive lifting is termed flame blow-off.

Flame speed: It is a measurement of rate of linear propagation of flame through gas-air mixture, measured in centimetre per second (cm/sec).

Flash back (Light back): Transfer of combustion from burner port to a point upstream in the gas/air flow into the mixing tube and usually to the injector.

Fuel-air ratio (FAR): It is the ratio between mass of fuel and the mass of air in the fuel-air mixture at any given moment.

Flue gases: Products of combustion including unused air.

Gas consumption rate: The amount of gas consumed in an appliance per unit of time, expressed as l/hr.

Gas flow meter: An instrument for measuring and sometimes recording the volume of gas which passes through it without interruption the flow of gas.

Heat flow: The transfer of energy due to the temperature difference is heat flow. One Watt is equal to 1 J/second of heat flow. One calorie is the amount of heat to raise one gram of water to one degree Celsius of temperature.

Heat rate: The amount of fuel energy burned to produce one kilowatt-hour of electrical output equivalent.

Injector jet: A jet removable and/or adjustable by means of which a calibrated amount of gas is allowed to pass through an orifice.

Luminance: It is a measure of the amount of light falling on a particular surface. Its unit is lux (lx), which is equal to one lumen per metre square ($1lm/m^2$).

Luminous efficiency (Shining efficiency): It is the measure of the efficiency of a device in converting electrical power to visible light and measured in lumens per Watt or lm/W.

Luminous flux: It is the light output defined as the luminous flux of a black body at 2042 ^oK per cm^2 and measured in lumen (lm).

Lux meter (Luminance meter): It measures the light falling on a given surface. b

Mixing tube: A tube connecting the injector and the burner ports, in which mixing of air and gas takes place.

Primary air: Air introduced into a gas stream before it leaves the burner port.

Secondary air: Air admitted to the combustion zone after combustion with primary air has commenced.

Soundness: Absence of external leakage greater than the permissible limit.

Specific gravity or relative density: The ratio of the mass of unit volume of dry gas to that of unit volume of dry air under the same condition of temperature and pressure.

Specific heat flow/capacity: It is an amount of heat required to change temperature of one kg of water by one degree of temperature and expressed in kW.

Stoichiometric mixture: Mixture of gas and air in proportions determined by the theoretical air requirement.

Thermal (heat) efficiency: It is the ratio of output heat to input heat when the combustion system is running under design conditions and expressed in percentage.

Throat: The inlet end of the mixing tube which has the smallest cross sectional area.

Turndown: It is the ratio of maximum heat release to the minimum heat release.

Acknowledgement

Biogas is increasingly becoming popular in several developing countries with a renewed focus on market based and carbon funding. SNV Netherlands Development Organisation is doing a yeoman's service in developing and implementing sizable biogas programs in many developing countries to brighten the life of rural women by empowering them to produce clean fuel and enriched organic fertiliser from the materials, such as cattle dung and organic wastes, available right in their backyards, along with achieving improved sanitation and environment.

One of the important yardsticks of the success of the biogas program is the efficient use of biogas as domestic fuel for cooking and lighting purposes. However, at present the appliances manufactured and supplied are largely not meeting the required quality mark.

For the first time in November 2007, SNV got testing of biogas stoves of eight countries and biogas lamps of four countries carried out at three well-known institutes; two located in developing countries and one in a developed country. We thank the scientists and engineers of theses institutes who conducted the testing of appliances and prepared reports.

Preparation of this popular summary, based on the test reports of the three institutes, was not an easy task. Each institute used its own methodology of testing and somewhat different terms for expression of results. The institutes located in China and India compared and commented upon the quality and performance of appliances with reference to the specifications followed in their respective country. As there were many variables in the test reports, not all could be included in this paper.

Analysis of very limited samples of appliances from a country might not reflect the prevailing actual status of biogas appliances in that country.

We are grateful to SNV for assigning the preparation of this summary paper. We hope that it would generate interest among stakeholders, in particular biogas appliance manufacturers and program administrators in drawing an action plan to improve quality of appliances and biogas use efficiency, which in turn would further improve the financial viability of biogas plants and result in increasing the monetary savings to biogas users. Recommendations are made from the viewpoints of improving designs of biogas stoves and lamps and their quality of production and marketing.

Special thanks are due to Mr. Wim van Nes, Biogas Practice Leader, Asia & Africa, SNV for providing test reports and a study on biogas stoves carried out in Nepal and for constant guidance and help. Comments and suggestions received from the testing institutes and reviewers, Mr Ramesh K. Gautam, Microfinance Advisor, SNV/Nepal and Mr Jan Lam, Biogas Advisor, SNV/Cambodia helped us greatly in improving the paper and we thank them profusely.

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Disclaimer

The views expressed are of the authors, not of their respective organisations and of SNV and its related organisations.

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Summary

SNV commissioned three institutes, namely Chengdu Energy Environment International Cooperation (CEEIC), Chengdu in line with Biogas Appliances Quality Inspection Center of the Ministry of Agriculture, People's Republic of China; Department of Renewable Energy Sources (DRES), College of Technology and Engineering, Maharana Pratap University of Agriculture and Technology, Udaipur, India; and Kiwa Gastec Certification (GASTEC), Apeldoorn, The Netherlands to test samples of biogas stoves obtained from eight countries (Bangladesh, Cambodia, Ethiopia, India, Lesotho, Nepal, Rwanda and Vietnam) and lamps from four countries (Cambodia, Ethiopia, India and Nepal). CEEIC followed testing procedure prescribed in the Chinese standard specifications meant for biogas stove and lamp. DRES used the procedure described in the Indian standard specification for stove and in-house procedure developed for lamp. GASTEC developed its own methodology for both stove and lamp.

The present popular summary provides information on properties of biogas, combustion and flame characteristics and designs of a typical burner and lamp. Comparisons of standard specifications of stoves prescribed in China and India and testing methodology used for stove and lamp have been attempted. The test results provided information on physical appearance, air tightness, biogas consumption (heat rate), flame transmission, combustion stability, thermal efficiency, concentration of carbon monoxide in smoke, wind resistance, fire resistance, surface temperature, noise, durability, structure, material and surface finishing, etc., besides marking, packaging and instructions for users of appliances. The standard specifications of China and India lay equal importance on a group of items or all items of test respectively. However, this paper lays focus on inlet gas pressure, gas consumption, flame transference, thermal/luminance efficiency, wind resistance and CO in smoke.

Summary of test results of both stoves and lamps obtained at three institutes is given country-wise. No stove qualified for quality certification under both the Chinese and the Indian standard specifications. Lamps did not qualify under the Chinese standard specification. The stoves from Bangladesh and Cambodia only met the prescribed minimum thermal efficiency of 55 per cent. Carbon monoxide concentration in smoke was found too high in all tested appliances. The lamp from Cambodia performed relatively better at CEEIC and DRES but not at GASTEC. The lamp from India gave better luminous efficiency at GASTEC but not at CEEIC and DRES. However, no lamp was free from problems.

Main problems identified with the tested stoves and lamps are enumerated and possible solutions thereto are mentioned. Recommendations are given for improving designs and quality of production of appliances. An urgent felt need is to develop a model standard specification, including testing methodology, for stoves and lamps suited to variable and high gas pressures of fixed dome plants, which are promoted under the biogas programs supported by SNV. Areas of applied R&D have also been identified.

Popular Summary of Test Reports on Biogas Stoves and Lamps prepared by testing institutes in China, India and the Netherlands

1. Introduction and background

1.1 Netherlands Development Organisation (SNV) is supporting national domestic biogas programs in six Asian (Cambodia, Bangladesh, Lao People's Democratic Republic, Nepal, Pakistan and Vietnam) and three African countries (Ethiopia, Tanzania and Rwanda) and more countries are likely to be covered in future. Aim is to disseminate domestic biogas plants as an indigenous and sustainable energy source through a commercial market oriented sector for improving living standard of rural families in developing countries. Fixed dome biogas plants of sizes ranging from 4 m^3 to 15 m^3 are promoted to produce about 1 m^3 to 4 m^3 gas per day. Biogas is used mainly in stoves for cooking purpose. To a lesser extent gas is used for lighting purpose in silk-mantle lamps. Quality of these appliances is important for satisfying the daily fuel needs of individual households, besides human safety and economic benefits. In fact, an important factor determining the success or failure of biogas program in a country is the ease of use, efficiency and durability of biogas appliances.

1.2 In 2007, SNV commissioned three institutes, namely Chengdu Energy Environment International Cooperation (CEEIC), Chengdu in line with Biogas Appliances Quality Inspection Center of the Ministry of Agriculture, People's Republic of China; Department of Renewable Energy Sources (DRES), College of Technology and Engineering, Maharana Pratap University of Agriculture and Technology, Udaipur, India; and Kiwa Gastec Certification (GASTEC), Apeldoorn, The Netherlands to test samples of biogas stoves and lamps. Samples of stoves were obtained in duplicate for each institute from eight countries, namely Bangladesh, Cambodia, Ethiopia, India, Lesotho, Nepal, Rwanda and Vietnam and lamps were procured from four countries, namely Cambodia, Ethiopia, India and Nepal.

1.3 The testing methodology was finalized in a meeting held at Apeldoorn, the Netherlands in June 2007. It was decided that CEEIC and DRES would follow respectively the testing procedures prescribed in the Chinese and Indian standard specifications meant for biogas stoves. For lamps, CEEIC was to follow the procedure prescribed in the standard specifications meant for China and DRES and GASTEC were to use methods developed in house. The institutes carried out testing of appliances in the months of August to October, 2007. The test reports were discussed in a joint program meeting held at Chengdu in November, 2007. After conducting some additional tests and verification of results, the institutes submitted final test reports in January, 2008. The reports were examined by the stakeholders involved in the countries concerned. Further results of the test reports were discussed in the Fifth Meeting of SNV External Biogas Network held at Vientiane, Lao People's Democratic Republic in April, 2008 and a follow up action plan was prepared (Anonymous, 2008).

2. Objectives

The present paper aims at preparing a popular compilation of the relevant information collected in the framework of the test work, comparing the results of the three institutes and providing main recommendations for activities to be conducted in the immediate future. It is intended to address the following areas:

- Brief description and comparison (similarities and differences) of the methodologies used by the institutes for testing of the biogas appliances;
- An overview of the test results of the biogas appliances by the three institutes with an explanation of the possible differences between results;
- An overview and an assessment of the recommendations provided by the three institutes on the possible improvement of the biogas appliances; and
- Conclusions on the usefulness of the tests of the biogas appliances and recommendations on activities to be conducted as a follow-up to these tests.

Part - I. General Information

3. Properties of Biogas

3.1 Biogas, which is produced from cattle dung, pig manure and other organic wastes in a specially designed anaerobic digester, commonly called as ‘biogas plant’, is a methane-rich fuel. Since biogas contains primarily methane and carbon dioxide, their physical and chemical properties and quantities will determine over all properties of biogas and in turn the choice of combustion device. Physical and chemical properties of methane and carbon dioxide are mentioned in Table 1 (GTRI, 1988).

Table 1 Physical and chemical properties of methane and carbon dioxide

Property	Methane (CH_4)	Carbon dioxide (CO_2)
Molecular weight	16.04	44.01
Specific gravity (Air = 1)	0.554	1.52
Boiling point at 760 mm	-161.49 ^oC	43.00 ^oC
Freezing point at 760 mm	-182.48 ^oC	-56.61 ^oC
Critical temperature	-82.5 ^oC	31.11 ^oC
Critical pressure	47.363 kg/cm^2	75.369 kg/cm^2
Heat capacity ratio	1.307	1.303
Heat of combustion	38.13 MJ/m^3	-
Limit of inflammability	5-15 % by volume	-
Stoichiometry in Air	0.0947 by volume or 0.0581 by mass	-
Ignition temperature	650 ^oC	-

3.2 Biogas produced in individual households can be used for cooking and/or lighting purposes. It burns as soot-less blue flame. Characteristics of biogas important from the viewpoint of designing an efficient stove or a lamp are mentioned at Table 2 (Nijaguna, 2006).

Table 2 Properties of biogas relevant for designing a stove or a lamp

Property	Value
Methane and carbon dioxide content	60 % and 40 % (v/v)
Calorific value	22 MJ/m^3
Specific gravity	0.940
Flame speed factor	11.1
Air requirement for combustion	5.7 m^3/m^3
Combustion speed	40 cm/sec.
Inflammability in air	6-25 %

3.3 Combustion

3.3.1 Combustion of methane

Understanding the combustion process provides a basis of performance criteria and emission standards used to regulate manufacturing and marketing of quality appliances. Biogas burns in oxygen to give carbon dioxide and water and energy content in methane is released.

The chemical reaction of biogas burning is mentioned below:

$$\underset{\text{(Gas)}}{CH_4} + \underset{\text{(Gas)}}{2O_2} \rightarrow \underset{\text{(Gas)}}{CO_2} + \underset{\text{(Water vapours)}}{2H_2O} + \underset{\text{(Heat and light)}}{\text{Energy}}$$

One volume of methane requires two volumes of oxygen to give one volume of carbon dioxide and two volumes of water vapours. Each m^3 of pure methane releases 36 MJ of energy.

However, generally the oxygen required for combustion is taken from air, which contains approximately 21 per cent oxygen and 79 per cent nitrogen by volume. The chemical reaction is depicted below:

$$CH_4 + 2\,O_2 + 7.5\,N_2 \rightarrow CO_2 + 2\,H_2O + 7.5\,N_2 + \text{Energy}$$

Thus, about 9.5 volumes of air per volume of combustion of methane are required to achieve complete oxidation. This is the stoichiometric methane-air mixture and is the optimum concentration of methane in air at which complete combustion occurs without unused air or fuel.

3.3.2 Characteristics of biogas

Biogas is a clean fuel – non toxic in nature, odourless and smokeless. Chemically it contains 55-70 per cent methane, 35-40 per cent carbon dioxide and less than 5 per cent of other gases, such as ammonia, hydrogen, carbon monoxide, nitrogen, etc. On complete combustion of biogas, the amount of energy released is about 20-24 MJ/m^3.

3.3.3 Biogas-air mixture for complete combustion

The combustion of gas involves mixing of air with fuel gas, adding heat in the form of a pilot and burning the resultant air-gas mixture. The chemical reaction of combustion of biogas (containing 60 % methane and 40 % carbon dioxide) and air mixture is shown below:

$$0.6\,CH_4 + 0.4\,CO_2 + 1.2\,O_2 + 4.5\,N_2 \rightarrow CO_2 + 1.2\,H_2O + 4.5\,N_2 + \text{Energy}$$

Thus, one volume of biogas requires 5.7 volumes of air or the stoichiometric requirement is $1/(1+5.7) = 0.149$, i.e., 14.9 per cent biogas in air.

The biogas burns over a narrow range of mixtures from approximately 9 per cent to 17 per cent of biogas in air. If the flame is 'too rich', i.e., has too much fuel, then it will burn badly and incompletely, giving carbon monoxide, which is poisonous and soot particles. Therefore, the designs of appliances should aim at to maximize the conversion of methane into carbon dioxide in order to minimize the release of unburned methane and products of incomplete combustion. Stoves usually run slightly lean with a small excess of air to avoid the danger of the flame becoming rich.

3.4 Flame

Biogas flame is cone shaped and consists of an inner cone and an outer mantle as shown in Fig.1 (Fulford, 1996). When biogas and air mixture reaches the burner ports and burnt with a pilot heat, it forms a cone shaped blue flame. The cone shape of the flame is a result of laminar flow in a cylindrical mixing tube. The unburned gas is heated up in an inner cone and starts burning at the flame front. The mixture at the centre of the tube moves at a higher velocity than at the outside. In the main combustion zone, gas burns in the primary air and generates heat in the flame and combustion is completed at the outer mantle of the flame with the aid of secondary air or the flame from the sides. With the vertical rise of combustion products, i.e., carbon dioxide and water vapours, heat is transferred to the air close to the top of the flame. The hot air, which moves vertically away, draws in cooler secondary air to the base of the flame. The size of the inner cone depends on the primary aeration. A high proportion of primary air makes the flame much smaller and concentrated, giving higher flame temperature. If combustion is complete, which requires a temperature of less than 850 ^{o}C and residence time of less than 0.3 second, the flame is dark blue and almost invisible in daylight. If too little air is available, then the gas does not burn fully and part of the gas escapes unused. With too much supply of air, the flame cools off and as a result the consumption of biogas is increased and the cooking time is prolonged. Further there is a risk of flame lifting which can result in undesirable high CO concentration.

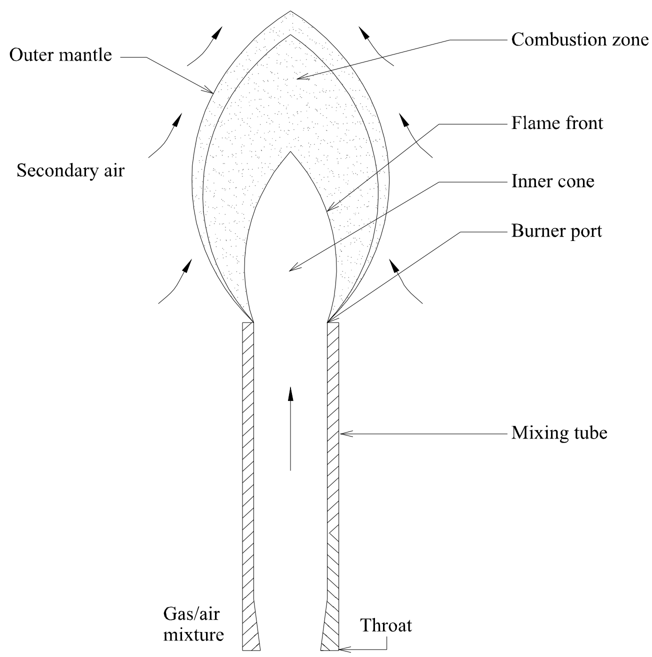

Fig.1 Biogas flame

3.5 Effect of carbon dioxide and water vapours contained in biogas

The large quantity of carbon dioxide present in biogas poses a threat to stable combustion of biogas. CO_2 traps not only heat but it also interacts with the flame which could potentially cool the flame down enough that it becomes unstable and blows out. Similarly, the water vapours present in biogas have a small but noticeable impact on flame temperature, inflammability limits, lower heating value and air-fuel ratio of biogas.

Part II - Biogas Stoves

4. General features

4.1 Biogas stove is a relatively simple appliance for direct combustion of biogas. Its burner is a premix and multi-holed burning ports type and operates at atmospheric low pressure. A typical biogas stove consists of gas supply tube, gas tap/valve, gas injector jet, primary air opening(s) or regulator, throat, gas mixing tube/manifold, burner head, burner ports (orifices), pot supports and body frame. Assembly of a typical biogas burner is shown at Fig.2. A biogas stove can have single or double burner, varying in capacity to consume from 0.22 to 0.44 m^3 of gas per hour or more.

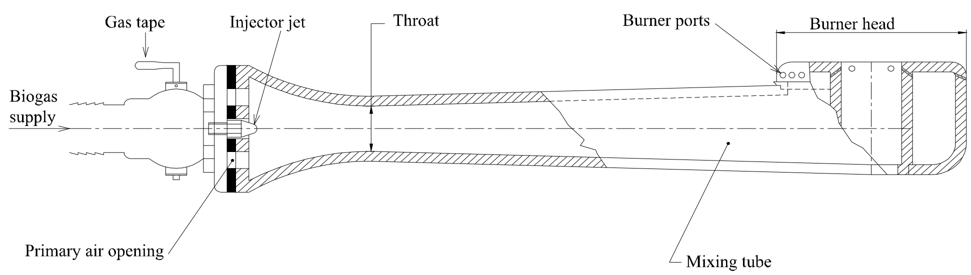

Fig.2 Assembly of a typical biogas burner

4.2 Biogas reaches with certain speed at the stove, depending on inlet gas pressure and diameter of gas supply pipe. With the help of an injector jet at the inlet of the stove, the gas speed is increased to produce a draft to suck primary air. The gas and air get mixed in the mixing tube and the diffused gas mixture goes into the burner head. The cone of the diffuse and the shape of the burner head are formed in such a way as to allow the gas pressure to equal everywhere before the mixture of gas and air leaves the burner through the ports with a speed only slightly above the specific flame speed of biogas. For the complete combustion of biogas, more oxygen is drawn from the surrounding air, called secondary air.

4.3 Main designing parameters

Main parameters for designing a biogas stove are efficiency and safety suiting to the kind of biogas plants being promoted, besides simplicity to mass manufacturing and cost effectiveness. For achieving a high efficiency, the important factors to be considered are:

- Gas composition,
- Gas pressure,
- Flame speed (velocity),
- Pan to burner distance, and

In general the stove should meet the criteria mentioned below:

- Gas inlet pipe should be smooth to minimize the resistance to flow of gas and air.

- Spacing and size of air holes should match with the requirement of gas combustion.
- Volume of burner manifold should be large enough to allow complete mixing of gas with air.
- Size, shape and number of burner port holes should allow easy passage of the gas-air mixture, formation of stabilized flame and complete combustion of gas, without causing lifting up of flame, off the burner port or flame back flash from burner port to gas mixing tube and injector jet. The flame should be self stabilizing i.e., flameless zones must re-ignite automatically within 2 to 3 seconds.
- Under ideal condition, the pot should be cupped by the outer cone of the flame without being touched by the inner cone.
- Size and shape of the burner.

To suit the high gas pressure in fixed dome biogas plants, Sasse, Kellner and Kimaro (1991) suggested different dimensions of stoves in terms of diameter of jet, length of intake holes measured from the end of jet, the length of mixing pipe and its diameter and number and diameter of flame port holes.

5. Standard specifications of stoves prescribed in China and India

5.1 National Standard Specifications of the People's Republic of China

The State General Administration of Quality Supervision and Inspection and Quarantine of the People's Republic of China approved the National Standards on Domestic Biogas Stoves-GB/T 3606-2001 (NSDBS, 2001) on November 12, 2001, which became applicable with effect from March 1, 2002. It states technical specifications, test methods and acceptance rules for domestic biogas stoves with a standard heat rate of a single burner not less than 2.33 kW. Stoves are tested with reference to: Appearance, air tightness, biogas consumption (heat rate), flame transmission, combustion stability, heat efficiency, concentration of carbon monoxide in smoke, wind resistance, fire resistance, surface temperature, noise, durability, structure, material and surface finishing, etc. It also provides information on marking on the stove, packaging requirements, operation instructions and transport and storage requirements. The procedure for testing of stoves for up to 708 l/hr declared flow rate given in the specifications was followed. Tests were carried out at the Biogas Appliances Quality Inspection Center of the Ministry of Agriculture, People's Republic of China located at Chengdu.

5. 2 National Standard Specifications of India

Biogas Stove Specification, 2002 (revised edition) of the Bureau of Indian Standards (BIS) is in force in India at present for quality certification purpose (BIS, 2002). It provides information on construction, operation and safety requirements and tests for stoves intended for use with biogas up to 708 litres per hour flow rate. DRES used the procedure of testing given in this specification.

5.3 A comparison of standard specification of stoves prescribed in China and India is given at Table 3.

Table 3 Comparison of specifications prescribed under the Chinese and the Indian standards

Parameter	Values in Chinese Standard specifications	Values in Indian Standard specifications
Gas composition	Reference gas: 60 % CH_4 + 40 % CO_2	Biogas from a 6 m^3 gas/day floating gas holder plant based on cattle dung (55 % CH_4+ CO_2 & other gases)
Hear rate for a single burner	Not less than 2.33 kW	At least 450 l/hr rating at 27 °C and 760 mm of mercury
Rated biogas pressure in front of stove	800 Pa or 1600 Pa	Gas inlet pressure of 747 Pa
Appearance	Free from obvious scratch or any other defect	All parts sound and of high standard of workmanship and appropriate finish
Air tightness	Leakage is less than 0.7 l/hr under a pressure of 4.2 kPa	Complete assembly shall be checked for gas leakage at 3.92 kN/m^2;
Biogas consumption	Total rated heat rate > ± 10 %	± 8 %; multi burner within + 5 % and -15 %
Flame transmission	Not to exceed 4 sec.	
Combustion stability	Uniform and stable flame; free of light back, flame lift or yellow flame	No soot formation and no flashback
Heat efficiency	Over 55 %	At least 55 %
CO concentration in smoke	Not to exceed 0.05 % (500 ppm)	Not to exceed 500 ppm
Surface temperature (Hand contacting position	For hand contacting position: Room temperature + 25°C for metal part and + 35 °C for non metal part	When operated for 2 hr, temperature of surfaces in normal use not exceed 60 °C and that of working surface not exceed 120 °C
Noise	Less than 85 dB	Not give undue or excessive noise
Durability	Plug valve confirm to air tightness after application of 6000 times	Rivets, fastening screws, plug, etc., not lead gas leakage; at least one gas tap for each burner;
Structure	Remain stable and reliable without tilting or sliding during operation; inner walls of burner shall be smooth without any burr; convenient to clean; pan stand not deform or damaged when applying a net load of 98.1 N on the stand.	Remain stable and not easily overturned; easy to clean; relative distance between the centres of the adjoining burners shall be not less than 250 mm; pan support shall hold a pan of 125 mm diameter over at least one burner without the use of loose rings and 150 mm diameter vessel remains stable over each burner; A load of 250 N per burner applied at the top surface for 5 minutes should not cause deflection of more than 4 mm and the distance between the opposite side shall not change more than 5 mm;
Material and surface finishing	Cast iron or steel or non-ferrous metal or corrosion resistant material; nozzles of metal with melting point over 500 °C; Burners and pot stand of metal with melting point of over 700 °C; biogas tubes of metal with melting point over 350 °C; cast iron products have a minimum wall thickness of 3 mm and free of casting air cavity; minimum wall thickness of stainless steel products shall be 0.3 mm; surface be treated by electric plating or enameling or other proper anti-rust material.	Rigid metal tubing be used for internal gas supplies integral with stove; Metal of main body of burner, including mixing tube and head have melting point not below 510 °C; Body of gas tap be made of brass or bronze and nozzles be made of free cutting brass or mild steel or stainless steel; If body is electroplated, the top flat surface have a coating of a minimum of 10 microns of nickel followed by 0.2 micron of minimum chromium; paints be resistant to abrasion and heating; Pipe/tube for main gas rail be of mild steel and its minimum wall thickness be 1.6 mm + no limit/- 0.15 mm;
Injector jet		Fixed calibrated type; dimensions of across flat be minimum of 10 mm, projection from face of mounting 6 mm nominal and threads of M 8x1; melting point of metal be not less than 650 °C;

6. Testing Methodology

6.1 CEEIC tested stoves as per the methodology applicable for certification of stoves in China (NSDBS, 2001). DRES followed the methodology applicable for certification of stoves in India (BIS, 2002). GASTEC developed its own methodology based on its experience with international and the European standards relating to domestic appliances using natural gas (Feltmann and Postma, 2008). Thus, there was no uniformity in the appliances testing methodology. The methodologies followed by the three institutes are summarized in Table 4. Schematic diagram of a testing set up used at DRES is given at Fig.3. The other two institutes used a similar set up with the reference gas and not a biogas plant. As the atmospheric temperatures and pressures were different at three locations in China, India, The Netherlands, the readings of heat input were calculated at standardized temperature and pressure (STP), i.e., 0 ^{0}C and 760 mm mercury, for comparing results.

Table 4 Comparison of important parameters of testing followed by the institutes

Item	CEEIC			DRES			GASTEC		
Testing gas	Reference gas: 21± 1 MJ/m^3 (60 % CH_4 + 40 % CO_2)			Biogas from cattle dung plant (55 % CH_4 + 45 % CO_2, tolerance ± 4 %)			Reference gas: 20.77 MJ/m^3 (60 % CH_4 + 40 % CO_2)		
Air tightness	Under air pressure of 4200 Pa			Under air pressure of 3920 Pa			With biogas at maximum pressure		
Gas consumption (heat rate)	Flow meter readings converted according to a formula in to biogas consumption			Give within ± 8 % of rated capacity in l/hr at 27 ^{o}C and 760 mm of mercury. When measured with compressed air at inlet pressure of 747 Pa, the recorded air flow was converted to biogas consumption by multiplying with a factor of 1.05.			At actual condition (21^{o}C temperature and 1026 mbar pressure) and at STP		
Flame stability	Operation at gas inlet pressure of 800 and 1600 Pa; flame be uniform, stable, free of light - back, flame lift or yellow flame			Operation at gas inlet pressure of 747 Pa without flame either blowing off or striking back			Operation at gas inlet pressure of 800 and 1600 Pa; flame be uniform, stable, free of light back, flame lift or yellow flame		
Heat efficiency tests	Aluminum pot			Aluminum pan			Aluminum pan		
	Heat rate (kW)	Pot dia. (cm)	Water (kg)	Gas rate (l/hr)	External pan dia. (cm ± %)	Water (kg)	Heat input (kW)	Internal pan dia. (cm)	Water (kg)
	2.33	24.0	5	366-420	24.5	4.8	1.67-1.98	24.0	4.8
	2.79	26.0	6	426-480	26.0	6.1	1.99 -2.36	26.0	6.1
	3.26	28.0	7.5	486-570	28.5	7.7	2.37- 4.2	26.0	6.1
CO content in smoke	Ring type sampler			Sampling hood			Sampling hood		
Wind resistance test	Under pressure of 0.5 times rated pressure			-			-		
Surface temperature test	Under pressure of 1.5 times rated pressure; 30 min after burning			Under 747 Pa; 2 hrs after operation			Under rated pressure by using thermocouple in a black test floor		
Noise test	Under pressure of 1.5 times rated pressure			Under 747 Pa			-		

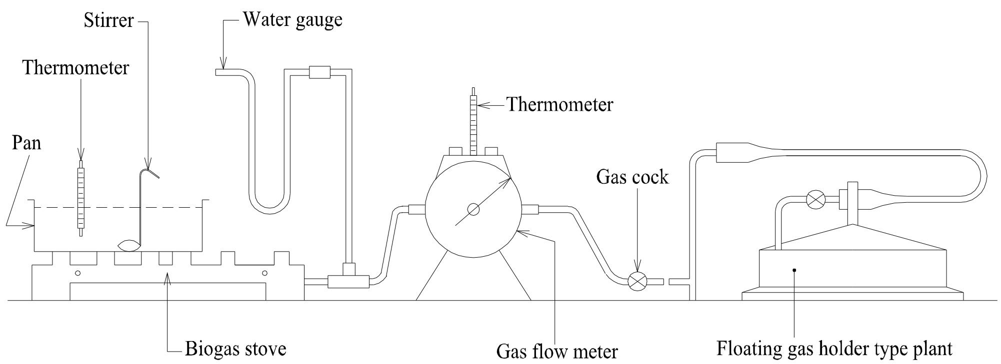

Fig.3 Schematic diagram of a testing set up for stove at DRES

6.2 Main differences in the methodology

The main differences in the methodology followed by three institutes are mentioned below:

- While CEEIC and GASTEC performed all testing work with the standard reference gas, containing 60 per cent methane and 40 per cent carbon dioxide, DRES used biogas (containing approximately 55 per cent methane and 45 per cent carbon dioxide subject to tolerance of ± 4 per cent carbon dioxide) produced from a 6 m^3 gas production per day capacity floating gas holder type plant based on cattle dung.

- Performance tests were carried out at inlet gas pressures of 800 and 1600 Pa at CEEIC and GASTEC. DRES calculated values for a pressure of 747 Pa.

- The three institutes used slightly different dimensions of the aluminum pans for the water boiling test for determining the thermal efficiency of stoves.

- The method of measuring CO and CO_2 in flue gases was different. GASTEC and DRES used hood while CEEIC used a copper round pipe with holes. GASTEC measured CO_2 value next to CO to determine the CO-air free value.

7. Limitations of Methodology

Limitations of the testing of appliances are mentioned below:

- Since stove manufactured by one firm was collected from a country, like India, Nepal and Vietnam, where many manufacturers are operating, the test reports did not reflect the over-all quality of appliances marketed in those countries.

- Some samples got damaged during transportation. In such cases, only one stove was tested.
- In the absence of documents, such as design parameters, users' instructions, drawings for assembling a given appliance, etc., in respect of certain samples, the institutes tested them as deemed optimally appropriate.

- Corrosion resistance test of burner crown and pan support (effect of burning of H_2S, whose concentration is relatively high in biogas produced from human waste) was not carried out by any institute.

- Names and addresses of the appliances manufacturing firms were not mentioned in the test reports, perhaps to maintain confidentiality.

- While stoves from some of the countries (e.g., Lesotho) were specially designed to suit high gas pressure of fixed dome plants, the testing was carried out at a relatively low inlet gas pressure.

- CEEIC and GASTEC tested the stoves with gas containing 60 per cent methane and DRES tested with gas containing 55 per cent methane. Whereas the methane content in biogas could be around 70 per cent under field conditions in fixed dome plants, designed for a long retention period as reported for the Lesotho stove (The high methane content could obviously give better thermal efficiency as compared to the test results).

- A high value of efficiency could be obtained at optimum burning under laboratory condition. However, in field, the efficiency of stoves depends upon environmental conditions, such as, wind, temperature and pressure; shape and specific heat capacity and weight of vessel; burner size of stove and size of bottom face of cooking vessel; and quantitative composition of different gases in biogas and respective calorific value used in the calculation of efficiency. Therefore, the thermal efficiency could be lower in field than the value obtained in controlled laboratory condition.

8. Measurements of sampled stoves

8.1 All the three institutes measured important parts of sampled stoves (Table 5). Photographs of stoves are shown at from Fig.4 to Fig.11. Some institutes found variations in certain features (e.g. number and diameter of holes for primary air and burner ports, crown diameter) between the two samples of the same stove type and manufacturer.

8.2 The differences observed in the measurements of critical parts of stoves, which determined the performance of stoves, reflected that the manufacturers of some of the countries such as Ethiopia, India and Vietnam, did not follow standard production practices.

Table 5 Measurements of stoves recorded at testing institutes

Parameter / Country	Burner type	Gas tap	Injector Body material/Dia. in mm			No. of holes for primary air/dia. of holes in mm (Area in mm^2)			Gas-air mixing tube: Length in mm/Dia. in mm	Number of ports/Dia. of port in mm/ Crown dia. in mm/Distance between pan and burner in mm		
			CEEIC	DRES	GASTEC	CEEIC	DRES	GASTEC	DRES	CEEIC	DRES	GASTEC
Bangladesh	Single	Needle	-2	Brass/2	Copper alloy/2	Nil	Nil	Closed	69/12	19/5.5/ 451 mm^2	19/5/ 75/35	20/5.3/ 76/34
Cambodia	Single	Nil	-/2.5	Mild steel/2.5	-/2.5	2/8 (100 mm^2)	2/8	2/8	150/15	20/5/ 392 mm^2	20/5/ 72/28	20/5.6/ 72/30
Ethiopia Big	Single	Nil	-/2.8	Brass/2	-/3	6/5 (117 mm^2)	5/5	6/7	93/17	193/3 1363 mm^2	193/3/ 160/42	169/2.9/ 200/41
Small	Single	Nil	-/1.9	Mild steel/3	Copper alloy/1.95	6/10 (471 mm^2)	6/6	4/(4-4.5)	110/50	16/2/ 50 mm^2	16/2/ 59/ 22	16/2/ 57/20
India	Double	Cock	-/2.5	Brass/2	Copper alloy /2.5	2/8 (100 mm^2)	Ring	-	86/18	20/5/ 392 mm^2	34/5/ 85/20	34/4.8/ 85/18.6
Lesotho	Single	Needle	-/1.6	Brass/2	Copper alloy/1.75	1/8 (50 mm^2)	1/7	Venturi	90/38	82/3/ 579 mm^2	84/2.5/ 125/45	82/2.5/ 126/45
Nepal	Single	Nil	-/2.5	-/2.5	-/2.4	2/8(100 mm^2)	-	2/7.1	135/18	20/5/ 392 mm^2	20/5/ 72/25	20/5/ 73/25
Rwanda	Single	Nil	Iron/1. 9	Mild steel/2	-/1.95	-/8.5 (2113 mm^2)	2/9	2/8.9	126/32	16/2.8/ 98 mm^2	17/3/ 115/40	17/3/ 116/40
Vietnam	Single	Needle	-/2.85	Brass/3	Brass/3	-/- (490 mm^2)	22/14	Venturi 16.6X23.4	120/18	50/2.5/ 245 mm^2	55/2/ 100/50	60/2.5/ 105/25

Fig.4 Stove from Bangladesh

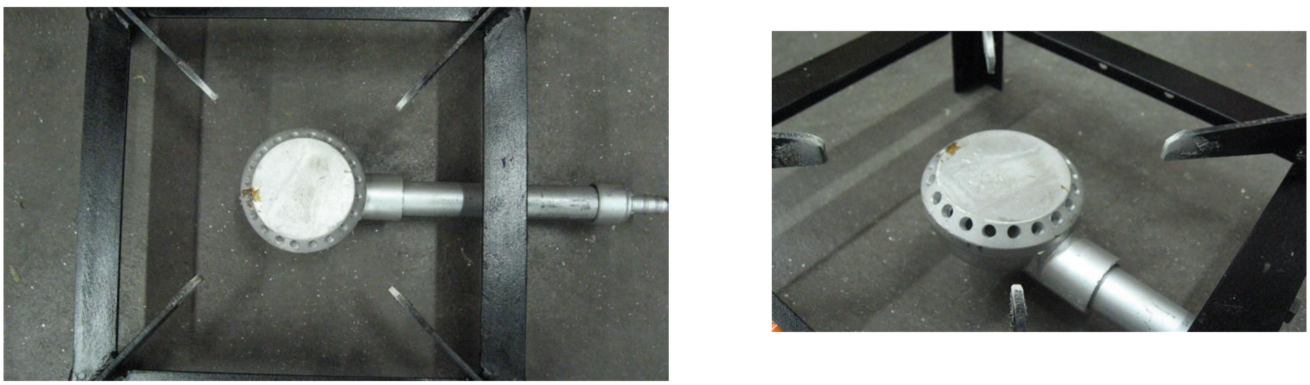

Fig. 5 Stove from Cambodia

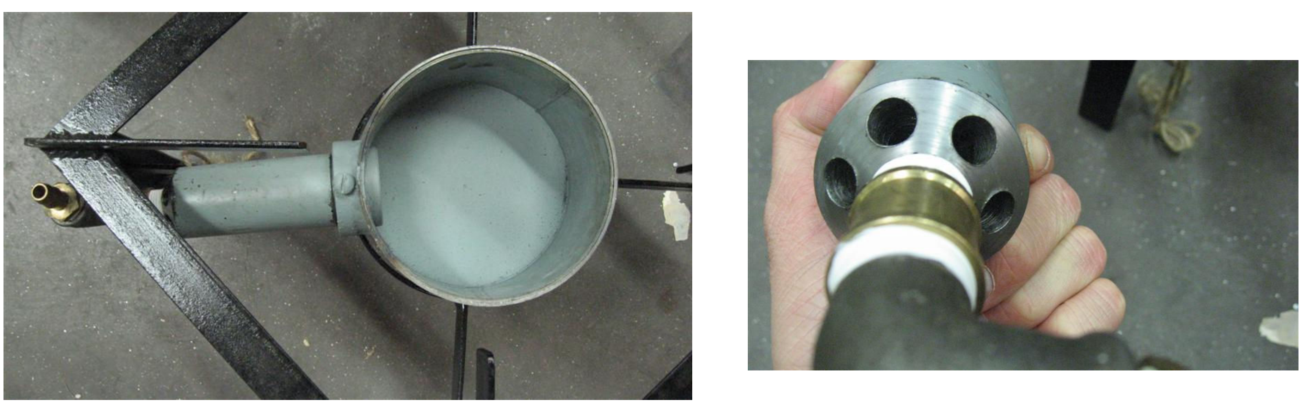

Fig.6 Stove from Ethiopia

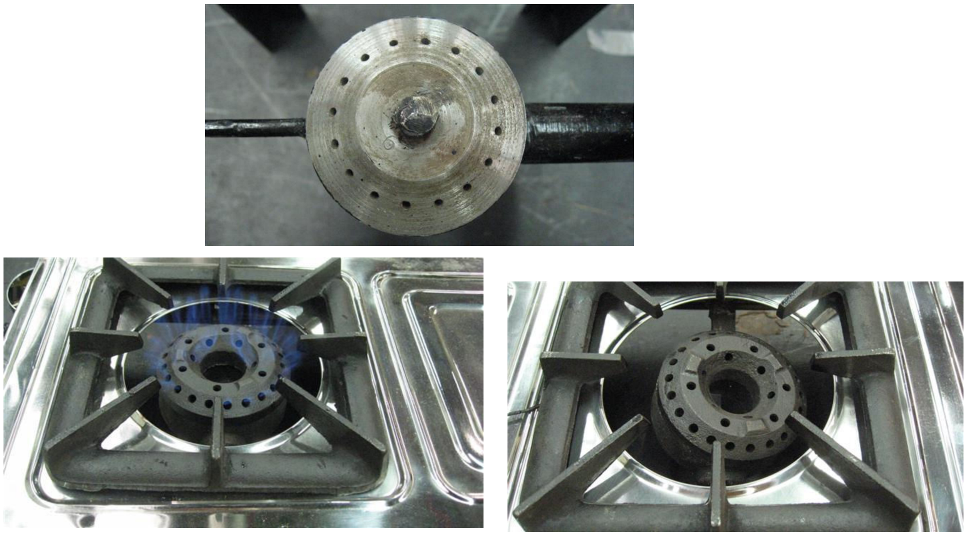

Fig.7 Stove from India

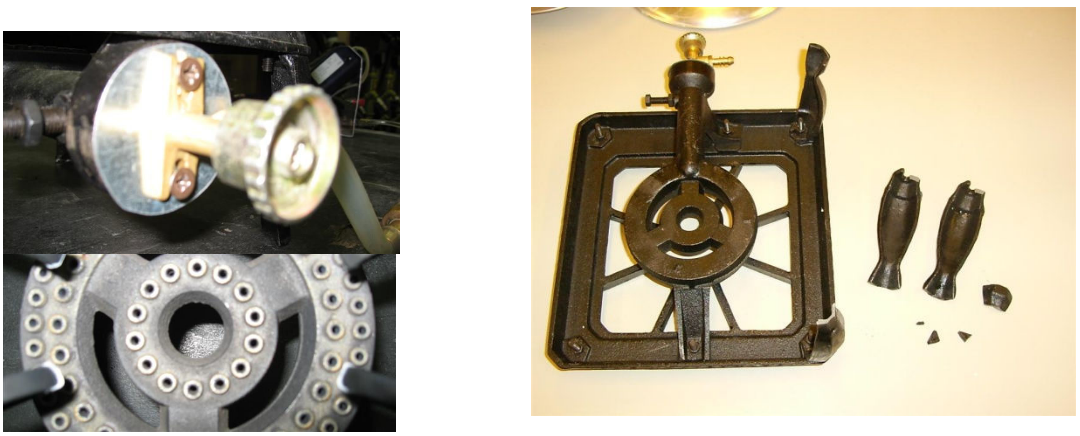

Fig.8 Stove from Lesotho

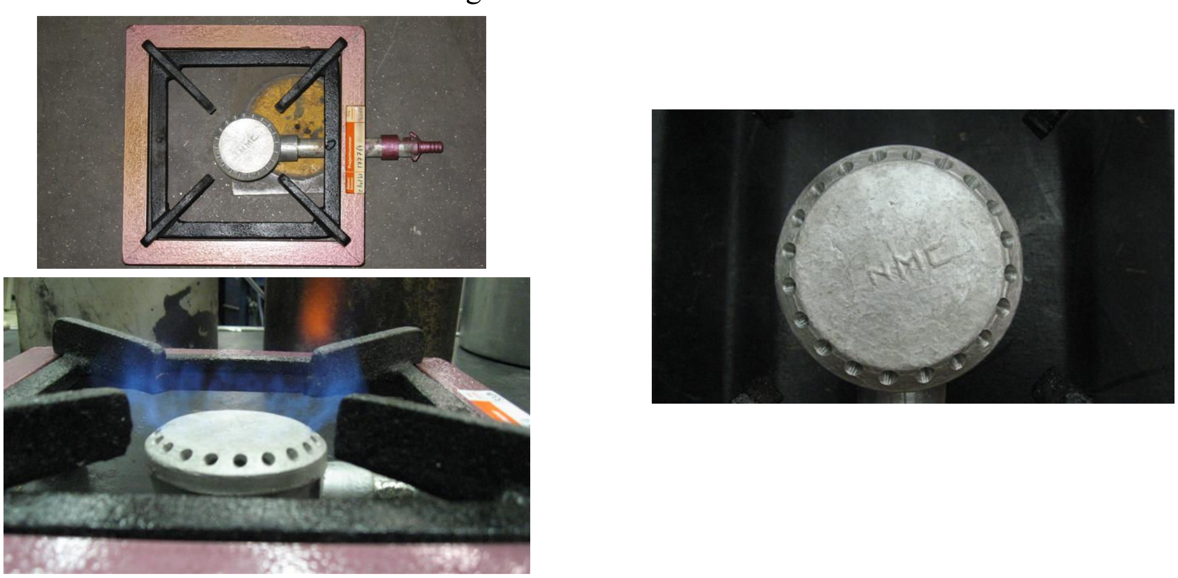

Fig.9 Stove from Nepal

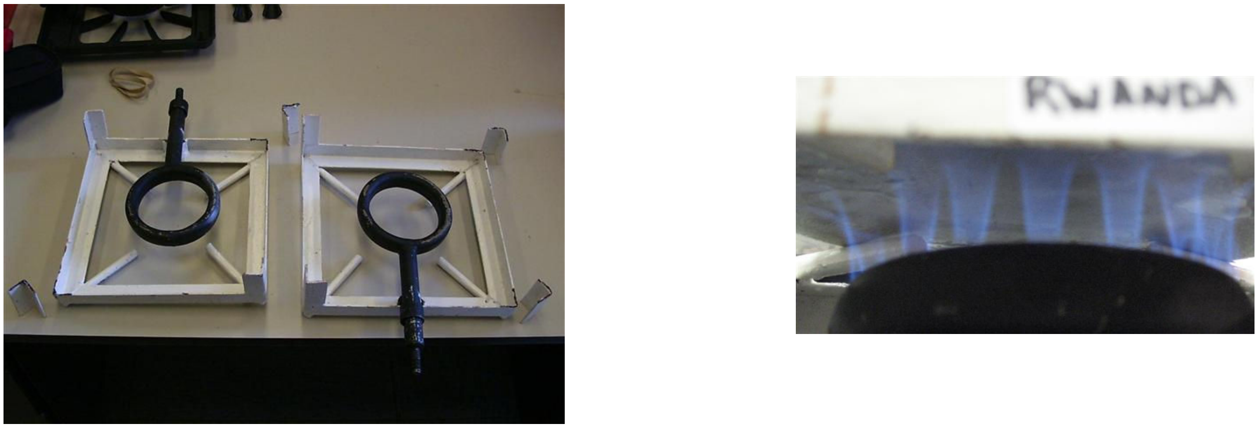

Fig. 10 Stove from Rwanda

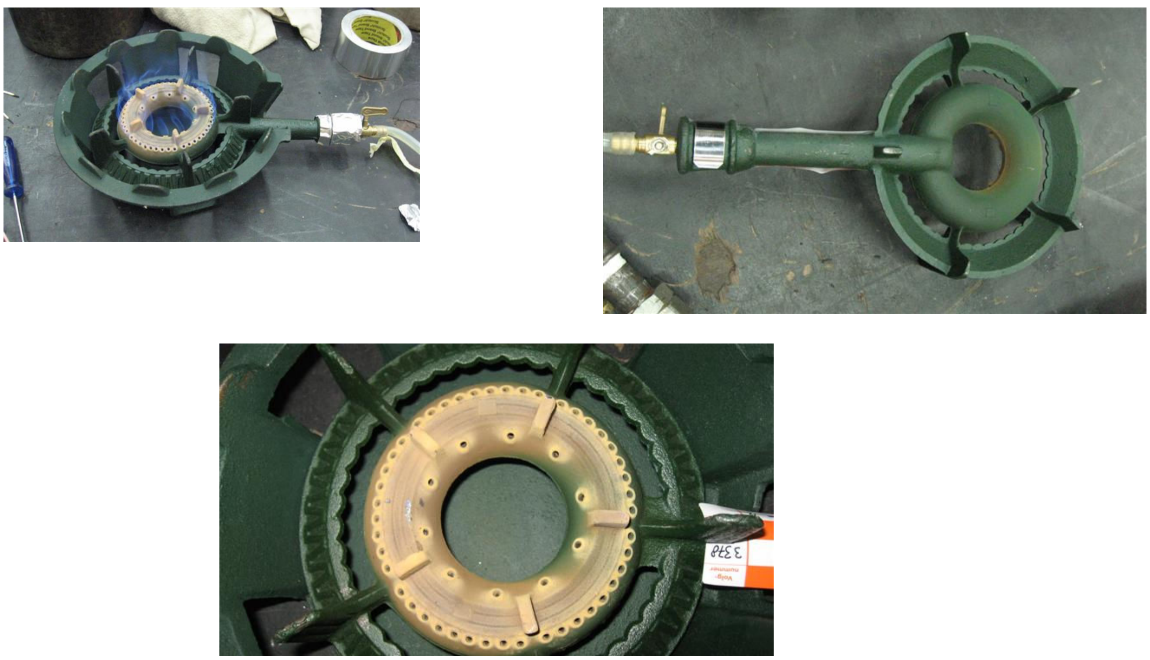

Fig.11 Stove from Vietnam

9. Test Reports

9.1 The reports prepared by the three institutes, namely CEEIC (Anonymous, 2007), DRES (Kurchania, 2007) and GASTEC (Feltmann and Postma, 2008) are summarized, country-wise, in the subsequent paragraphs

9.2 Summary of Test Results

9.2.1 Bangladesh

CEEIC and GASTEC reported data for two levels of heat flow, called here as low and high heat flows, while DERS tested at one level of heat flow. The test results are summarized in Table 6. The stoves showed more than the prescribed 55 per cent of thermal efficiency but did not qualify to the standards prescribed in China and India, mainly due to poor casting of the burner, needle type gas tap, high heat input, low wind resistance, and high emission of CO in smoke than that of the prescribed limits.

Table 6 Comparison of results of the stove of Bangladesh

Parameter	Unit	Value				
		CEEIC		DRES	GASTEC	
Rated heat flow	kW	2.33 (Low)	2.79 (High)	-	Low	High
Inlet gas pressure	Pa	1600	1600	747	800	1600
Pan size (diameter)	mm	240	240	180	240	240
Gas consumption	l/hr	425.5	474.5	211	349	500
Heat input	kW	2.06 (2.33)	2.35 (2.33)	-	1.98	
Flame transference	sec	2 (4)	2 (4)	2	-	-
Thermal efficiency	%	57 (55)	57 (55)	64.5 (55)	65.8	52.1
Flame temperature	^{o}C	-	-	625	620	675
Flame stability without pan		Stable	Stable	Stable	Stable	Stable
Wind resistance - Flame extinguished (Yes/No) at speed	m/sec	Yes	Yes	Yes, >2	Yes, 1.7	Yes, 1.8
CO emission in smoke	ppm	478 (<165)	>1180	5300 (500)	544	2800
CO emission (air free)	ppm	-	-	-	1821	6841
Qualified to standards (Yes/No)		No	No	No	-	-

Note: Figure given in parenthesis is the minimum value prescribed in the standards.

9.2.2 Cambodia

Summary of test results is given at Table 7. The stoves qualified on the ground of thermal efficiency but did not meet other minimum requirements relating to heat input, wind resistance and CO emission in smoke as prescribed in the standard specifications of China and India.

Table 7 Comparison of results of the stove of Cambodia

Parameter	Unit	Value				
		CEEIC		DRES	GASTEC	
Rated heat flow	kW	2.33 (Low)	2.79 (High)	-	Low	High
Inlet gas pressure	Pa	1600	1600	747	800	1600
Pan size (diameter)	Mm	240	240	260	260	260
Gas consumption	l/hr	672	762	489	579	808
Heat input	kW	3.33 (2.33)	3.78 (2.33)	-	3.24	4.55
Flame transference	Sec	2 (4)	2 (4)	2	-	-
Thermal efficiency	%	58 (55)	55 (55)	48.1 (55)	47.8	45.6
Flame stability without pan		Stable	Stable	Unstable	Stable	Stable
Wind resistance - Flame extinguished (Yes/No) at wind speed	m/sec	Yes	Yes	Yes, >2	Yes, 3.3	Yes, 3.8
CO emission in smoke	Ppm	478 (<165)	>1180	2200 (500)	2210	1700
CO emission (air free)	Ppm	-	-		4162	2439
Qualified to standards (Yes/No)		No	No	No	-	-

Note: Figure given in parenthesis is the minimum value prescribed in the standards.

9.2.3 Ethiopia

The test results of big and small sized stoves are mentioned in Table 8 and Table 9 respectively. Both small and big sized stoves did not qualify the standard specifications of China and India, as they did not meet the requirements of heat flow, wind resistance and CO emission in smoke.

Table 8 Comparison of results of the big sized stove of Ethiopia

Parameter	Unit	Value		
		CEEIC	DRES	GASTEC
Rated heat flow	kW	3.26	High	High
Inlet gas pressure	Pa	800	747	16000
Pan size (diameter)	Mm	300	285	300
Gas consumption	l/hr	752	555	930
Heat input	kW	3.74 (2.33)	-	5.35
Flame transference	Sec	2 (4)	2	-
Thermal efficiency	%	51 (55)	45.1 (55)	47.8
Flame stability without pan		Stable	Stable	Stable
Wind resistance - Flame extinguished (Yes/No) at wind speed	m/sec	Yes	Yes >2.5	Yes 2.5
CO emission in smoke	Ppm	>340 (<165)	650 (500)	420
CO emission (air free)	Ppm	-	-	752
Qualified to standards (Yes/No)		No	No	-

Note: Figure given in parenthesis is the minimum value prescribed in the standards.

Table 9 Comparison of results of the small sized stove of Ethiopia

Parameter	Unit	Value		
		CEEIC	DRES	GASTEC
Rated heat flow	kW	2.79 (Low)	Low	Low
Inlet gas pressure	Pa	800	747	800
Pan size (diameter)	Mm	240	260	260
Gas consumption	l/hr	252.5	537	633
Heat input	kW	1.26 (2.33)	-	3.61
Flame transference	Sec	2 (4)	>4	-
Thermal efficiency	%	53 (55)	40.5 (55)	41.2
Flame stability without pan		Stable	Unstable	Stable
Wind resistance - Flame extinguished (Yes/No) at wind speed	m/sec	Yes	Yes >2	Yes 4.3
CO emission in smoke	ppm	>1180 (<165)	4350 (500)	4463
CO emission (air free)	ppm	-	-	6724
Qualified to standards (Yes/No)		No	No	-

Note: Figure given in parenthesis is the minimum value prescribed in the standards.

9.2.4 India

Summary of test results of a double-burner stove is given at Table 10. It did not qualify the Chinese and Indian standards, mainly in terms of heat flow, wind resistance and CO emission. The thermal efficiency of 89.9 per cent obtained at GASTEC with reduced rate of gas flow, by keeping the gas tape at low rate (simmering) position, is unusual for the water boiling test (Such a value is possible with complete combustion of gas and negligible loss of heat of transfer).

Table 10 Comparison of results of the double burner stove of India

Parameter	Unit	CEEIC Burner location		DRES Burner location	GASTEC Burner location	
		Left side	Right side	Both sides	Left side	Right side
Inlet gas pressure	Pa	1600	1600	747	800	800
Pan size diameter	Mm	300	300	245	260	260
Gas consumption	l/hr	731.5	597.0	400	472	261
Heat input	kW	3.67 (2.33)	3.0 (2.33)	-	2.68	1.49
Flame transference	Sec	2 (4)	2 (4)	3	-	
Efficiency (%)	%	53 (55)	57 (55)	54.5 (55)	53.9	89.9
Flame stability		Stable	Stable	Stable		
Wind resistance - Flame extinguished (Yes/No) at wind speed	m/sec	Yes	Yes	Yes, >2	Yes, 5.5	Yes, 5.5
CO emission in smoke	ppm	>1180 (<165)	>1180	2840 (500)	2900	85
CO emission (air free)	ppm	-	-	-	5090	349
Qualified to standards (Yes/No)		No	No	No	-	-

Note: Figure given in parenthesis is the minimum value prescribed in the standards.

9.2.5 Lesotho

The test results are summarized at Table 11. The stove did not meet the requirements of standard specifications of China and India mainly in terms of heat flow, thermal efficiency and wind resistance.

Table 11 Comparison of results of the stove of Lesotho

Parameter	Unit	Value		
		CEEIC	DRES	GASTEC
Inlet gas pressure	(Pa)	1600	747	1600
Pan size diameter	(mm)	240	180	240
Gas consumption	(l/hr)	270.5	217	354
Heat input	(kW)	1.34 (2.33)	-	2.0
Flame transference	sec	2	2 (4)	2 (4)
Efficiency	(%)	41(55)	45.1(55)	45
Flame stability		Stable	Unstable without pan	Stable
Wind resistance - Flame extinguished (Yes/No) at wind speed	m/sec	Yes	Yes, >2.5	Yes, 2.2
CO emission in smoke	ppm	28 (<165)	4350 (500)	8
CO emission (air free)	ppm	-	-	35
Qualified to standards (Yes/No)		No	No	-

Note: Figure given in parenthesis is the minimum value prescribed in the standards.

9.2.6 Nepal

The test results are summarized at Table 12. The stove did not meet the requirements of standard specifications of China and India mainly in terms of heat input, heat flow, wind resistance and CO emission.

Table 12 Comparison of results of the stove of Nepal

Parameter	Unit	Value recorded at different institutes		
		CEEIC	DRES	GASTEC
Inlet gas pressure	Pa	800	700	800
Pan size diameter	mm	260	260	260
Gas consumption	l/hr	565.5	453	536
Heat input	kW	2.81(2.33)		3.0
Flame transference	sec	2	2 (4)	2 (4)
Efficiency	%	55 (55)	42.1 (55)	42.2
Flame stability		Stable	Stable	Stable
Wind resistance - Flame extinguished (Yes/No) at wind speed	m/sec	Yes	Yes, >2.5	Yes, 2.2
CO emission in smoke	ppm	>1180 (<165)	4350 (500)	2140
CO emission (air free)	ppm	-	-	4347
Qualified to standards (Yes/No)		No	No	-

Note: Figure given in parenthesis is the minimum value prescribed in the standards.

9.2.7 Rwanda

Summary of the results is given at Table 13. The stove did not pass the standards of China and India in terms of heat value, heat flow, wind resistance and CO emission. It did not meet the requirement of thermal efficiency of the Indian standard.

Table 13 Comparison of results of the stove of Rwanda

Parameter	Unit	Value		
		CEEIC	DRES	GASTEC
Inlet gas pressure	Pa	800	747	800
Pan size diameter	mm	240	205	240
Gas consumption	l/hr	340.0	285	336
Heat input	kW	1.70 (2.33)	-	1.91
Flame transference	sec	2	3 (4)	2 (4)
Efficiency	%	60 (55)	53.8 (55)	54.6
Flame stability		Stable	Unstable without pan	Stable
Wind resistance - Flame extinguished (Yes/No) at wind speed	m/sec	Yes	Yes, 2	Yes, 0.5
CO emission in smoke	ppm	>1180 (<165)	2250 (500)	2200
CO emission (air free)	ppm	-	-	5035
Qualified to standards (Yes/No)		No	No	-

Note: Figure given in parenthesis is the minimum value prescribed in the standards.

9.2.8 Vietnam

Summary of the test results is given at Table 14. The stove did not meet the requirements of standards of both China and India in terms of heat value, heat flow, wind resistance and thermal efficiency.

Table 14 Comparison of results of the stove of Vietnam

Parameter	Unit	Value		
		CEEIC	DRES	GASTEC
Inlet gas pressure	Pa	800	747	1600
Pan size diameter	mm	300	295	300
Gas consumption	l/hr	758.0	620	1039
Heat input	kW	3.76 (2.33)	-	5.88
Flame transference	sec	2	4 (4)	2 (4)
Efficiency	%	39 (55)	21.2 (55)	31.5
Flame stability		Stable	Stable	Unstable
Wind resistance - Flame extinguished (Yes/No) at wind speed	m/sec	Yes	No, 5	Yes, 3.4
CO emission in smoke	ppm	>1180 (<165)	4350	1100
CO emission (air free)	ppm	-	-	1566
Qualified to standards (Yes/No)		No	No	-

Note: Figure given in parenthesis is the minimum value prescribed in the standards.

9.3 Limitation of summary tabulations

The limitations of preparing summary tables are mentioned below:

- The summary tabulations do not provide information on certain items of tests, such as, flame temperature, working surface temperature, noise, marking, packaging, instructions for users, etc.

- For flame temperature, GASTEC observed that it fluctuated over a large temperature range and those values would not provide additional useful information. Flame temperature is not measured under the Chinese standard specification.
- Out of the test results of duplicate sample, data of the stove, which gave higher thermal efficiency, are mentioned in the summary tables.
- Summary tables focus on thermal efficiency of stoves, as prescribed in the standards of China and India. However, under field conditions, the cooking efficiency of stoves, in terms of time taken in cooking of common dishes and the use of thermal energy, is more important than the tested thermal efficiency, as these two values could differ substantially.

9.4 Problems identified

A list of problems identified with the tested stoves is given at Table 15.

Table 15 Main problems identified in the sample stoves

Country of origin of stove	Problems with the stove
Bangladesh	• Jet hole not in the centre • Low heat flow • Poor casting of burner • Not uniform size of burner ports; • No air-intake • Needle type gas tap, requiring frequent lubrication
Cambodia	• Low height of pan support • No gas tap • No air-intake • Small diameter of injector jet
Ethiopia Big sized	• No gas tap • Only 60 % burner ports worked • Small height of pan support
Small sized	• Stove made of ordinary quality iron tubes; • No gas tap • Gas leaked at air-intake • Big air-intake size • Low heat flow • Improper burner ports causing poor transmission of flame
India	• Air intake small and not adjustable; • High heat flow with low heat efficiency • Big diameter of injector jet
Lesotho	• Too low heat flow due to small size of jet • Improper position of air intake hole • Big height of pan support
Nepal	• Small size air intake • Small height of pan support • No gas switch • Low height of base support
Rwanda	• Burner made of copper pipe with one-time air intake • No gas tap • Low heat flow • Small combustion area • Difficulty in cleaning burner • Small height of base support
Vietnam	• Small combustion area • Large sized air-intake hole • Weak air adjustable ring • Difficulty in cleaning burner • Small height of base support • Big diameter of injector jet

Part III - Biogas Lamps

10. General features

10.1 Biogas can be burnt in lighting mantles. A biogas lamp consists of gas supply tube, a gas regulator, gas injector jet, primary air hole (s) or air regulator, a clay nozzle, a silk mantle, a lamp shade and a glass shade. Schematic diagram of a biogas lamp is shown at Fig.12.

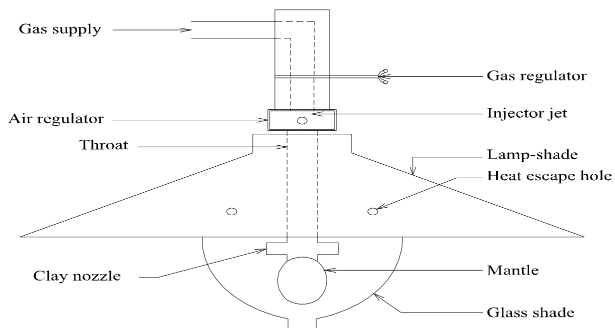

Fig.12 Schematic diagram of a biogas lamp

10.2 Mantles are made by saturating a ramie-based artificial silk or rayon fabric with rare earth oxides (cerium and thorium). It resembles a small net bag. A binding thread made of ceramic fiber thread is provided for tying it onto the mud head. When heated at a temperature of more than 1000 ^{o}C, the mantle glows brightly in the visible spectrum while emitting little infrared radiation. Fabric of the mantle, when flamed for the first time, burns away, leaving a residue of metal oxide. Therefore the mantle shrinks and becomes very fragile after its first use.

10.3 Since thorium is radioactive material it should be handled with utmost care. The particles from thorium gas mantles could fall out over time and get into the air where they could be inhaled. Also of concern is the release of thorium bearing dust if the mantle shatters due to mechanical impact. Alternative material which could be used is yttrium or zirconium, although they are either more expensive or less efficient.

10.4 The principal of a gas lamp is similar to that of the stove. In a lamp, the burning gas heats a mantle until it glows brightly. The key factors which determine the luminous efficiency are the type and size of mantle, the inlet gas pressure and the fuel-air mixture. The hottest inner core of the flame, should match exactly with the form of the mantle (Fig. 13). If the mantle body is too large, it will show dark spots. If the flame is too large, then gas consumption will be too high for the light flux yield. If the inlet gas pressure is below 75 mm WG, the lighting is poor (Nijaguna, 2006). The lighting is satisfactory if the gas pressure is above 100 mm WG and excellent at 150 mm WG. If the flame is too large, then gas consumption will be too high for the light flux yield. The maximum light flux values that can be obtained with biogas are 400-500 lumens, corresponding to luminous efficiency in the range of 1.2 to 2.0 lm/W and equivalent to those of a normal 25-75 W incandescent light bulb (Werner, Stohr and Hees, (1989).

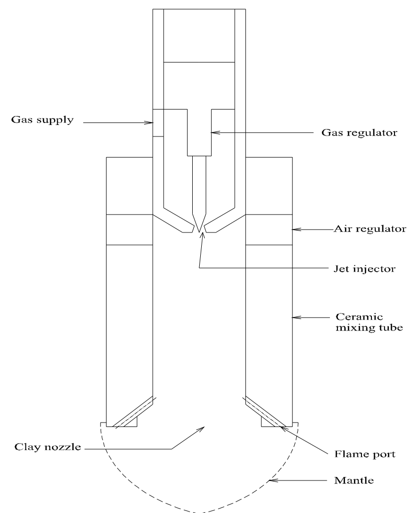

Fig.13. Design of a biogas lamp.

11. Standard specification

Standard specification has been developed for household biogas lamps in China and is in force for certification purpose. The ‘Household Biogas Lamps - Industry Standard (NY/T 344-1998) of China’ provides information on a classification of lamps based on gas presssure and heat value, performance requirements, test methods, marking, packaging, etc. (Annonymous, 1998). The standard is meant for lamps of less than 2400 Pa gas pressure and heat value of less than 525 W (450 kcal/hr). Lamps are tested at a rated gas pressure of 2400 Pa, 1600 Pa and 800 Pa and specified heat load in the range of 350 to 525 W. Methodology is given for determining burning stability, luminance, shining efficiency, content of CO in flue gas, noise, surface temperature, effect of mantle cover on luminance, etc. Requirements for lamp structure, regulations, marking and packaging are also mentioned. India has not developed or prescribed any standards for biogas lamps.

12. Measurements of sampled lamps

Measurements of samples are mentioned in Table 16 and photographs of lamps are shown at from Fig.14 to Fig.17.

Table 16 Measurements of biogas lamps

Parameter	Value recorded for lamps originated from different country			
	Cambodia	Ethiopia	India	Nepal
Diameter of gas nozzle jet (mm)	1	1.5	1.5	2
Air intake diameter (mm)	6	5	5	7
Number of holes for primary air	2	1	4	-
Clay venture				
Length (mm)	28	26	34	25
Diameter (mm)	20	15	13	14
Number of holes	61	37	18	36
Hole diameter (mm)	1.5	1	1.5	2
Cover				
Material	Glass	Glass	Mica	Glass
Diameter (mm)	100	105	100	107
Thickness (mm)	2	3	3	2

Fig.14 Lamp from Cambodia

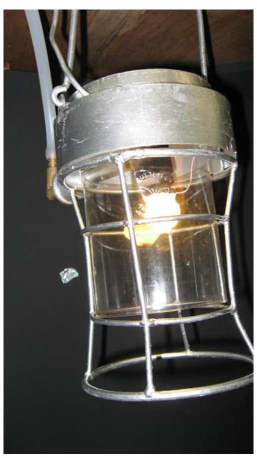

Fig.15 Lamp from Ethiopia

Fig.16 Lamp from India

Fig.17 Lamp from Nepal

13. Testing Methodology

As in case of stoves, testing of lamps was carried out at the Biogas Appliances Quality Inspection Center of the Ministry of Agriculture, People's Republic of China located at Chengdu in association with CEEIC. It tested lamps as per the methodology applicable for certification of biogas lamps in China (Anonymous, 1998). DRES (Kurchania, 2007) and GASTEC (Feltmann and Postma, 2008) used their own methodology. Schematic diagram of testing set up at CEEIC is given at Fig. 18. Black test box used for obtaining lux values at GASTEC is shown at Fig.19.

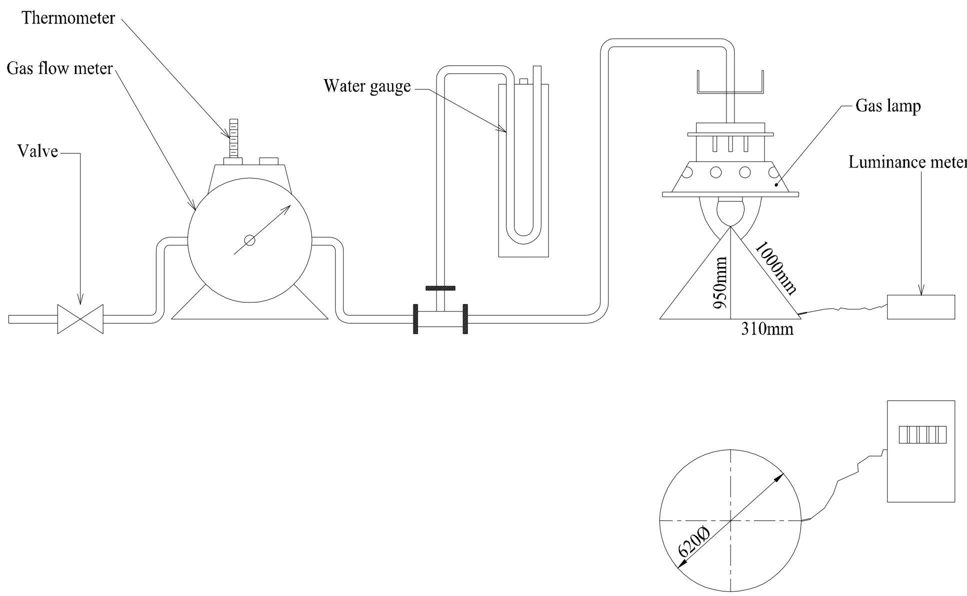

Fig.18. Schematic diagram of a testing set up for lamp at CEECI

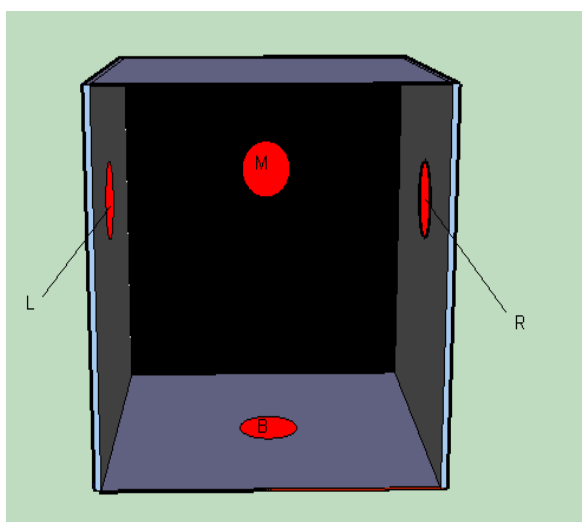

Fig.19 Black test box for measuring lux value of biogas lamp at GASTEC

14. Test Results

14.1 A comparison of test results of lamps is given at Table 17. The lamp from Cambodia performed relatively better at CEEIC and DRES but not at GASTEC. The lamp from India gave better luminous efficiency at GASTEC but not at CEEIC and DRES. However, no lamp was free from problems.

14.2 Problems identified in lamps

Summary of the main problems identified are mentioned in Table 18.

Table17 Comparison of test results of lamps

Country	Parameter	CEEIC	DRES	GASTEC
Cambodia	Gas pressure (Pa)	1600	747	1600
	Heat load (W)	326	200	320
	Gas consumption (m^3/hr)	0.055	0.037	0.056
	Illumination (Lu)	24	41	112-140
	Efficiency (Lu/W)	0.07	0.180	0.381
Ethiopia	Gas pressure (Pa)	Not tested; Flame backfired	747	1600
	Heat load (W)	-	195	360
	Gas consumption (m^3/hr)	-	0.036	0.059
	Illumination (Lu)	-	42	62-78
	Efficiency (Lu/W)	-	0.182	0.191
India	Gas pressure (Pa)	1600	747	1600
	Heat load (W)	556	400	690
	Gas consumption (m^3/hr)	0.093	0.072	0.113
	Illumination (Lu)	32	49	56-230
	Efficiency (Lu/W)	0.055	0.122	0.568-1.270
Nepal	Gas pressure (Pa)	800	747	800
	Heat load (W)	1510	340	390
	Gas consumption (m^3/hr)	0.245	0.062	0.065
	Illumination (Lu)	10	40	36-61
	Efficiency (Lx/W)	0.007	0.112	0.103-0.119

Table 18 Problems identified in the tested lamps

Country	Problems identified with the lamp
Cambodia	• Jet, injecting distance, size of mud head and mantle were not properly matching • Air regulator and reflector need improvement • Protection over glass not provided
Ethiopia	• Not designed properly • Made of cast iron • Air intake, reflecting cover, smoke exhausting hole and heat diffusing board not provided
India	• Gas flow adjustment provided but mud head was very small • Heat load near normal valve • Complex structure and self weight heavy • Costly rare metals used • Temperature at the upper part reached high
Nepal	• Mud head was small • Mantle not matched • Temperature at upper part reached very high

Part- IV. An Overview of Conclusions and Recommendations

15 Conclusions

15.1 The testing of biogas stoves developed and manufactured in eight developing countries and lamps in four countries was carried out at three well-known institutes, located in People's Republic of China, India and the Netherlands. This was an attempt made for the first of time by SNV to determine the efficiency and the quality of biogas appliances, which directly influence the acceptance of biogas technology.

15.2 In both People's Republic of China and India, standard specifications for biogas stoves have been formulated and are in force for quality certification. Testing facilities have been established by the respective Governments. China also has standards for biogas lamps. These standards provide information on testing procedures and are applicable for testing of appliances manufactured or marketed in the respective countries.

15.3 CEECI used the testing methodology as mentioned in the Chinese standards. DRES used the methodology for testing of stoves as given in the Indian standards. For lamps DRES designed its own methodology. Similarly, GASTEC developed methodology based on its experience in testing and certification of natural gas based domestic appliances for the European market.

15.4 The test results of stoves provided information on physical appearance, air tightness, biogas consumption (heat rate), flame transmission, combustion stability, thermal efficiency, concentration of carbon monoxide in smoke, wind resistance, fire resistance, surface temperature, noise, durability, structure, material and surface finishing, etc., besides marking, packaging and instructions for users of appliances. The standard specifications of China and India lay equal weight age on each item of tests and a stove or a lamp can be disqualified to quality-certification even if it fails to meet the prescribed minimum limit under any one item or group of items.

15.5 However, this paper lays focus on inlet gas pressure, gas consumption, flame transference, thermal efficiency, wind resistance and CO in smoke and information on appearance, air tightness, flame temperature, noise, surface temperature, etc., has been excluded. Values of different performance parameters relating to the best thermal/luminance efficiency of a given appliance are mentioned in the present paper.

15.6 Measurements of stoves

Variations were recorded in certain physical parameters, such as jet size, number of ports, etc., which are critical in determining thermal efficiency, between the duplicate samples received from some countries at a given institute. This reflected that manufacturers in countries, such as Ethiopia, India and Vietnam were not following standard practices for manufacturing stoves.

15.7 Conclusion of test results

- Most of the samples of stoves were not having any gas tap.

- Some of the stoves had needle type gas tap, which would require frequent servicing, i.e., lubrication.
- All samples of stoves and lamps did not qualify the standards of both People's Republic of China and India.
- On the basis of thermal efficiency alone, the stoves from Bangladesh and Cambodia met the prescribed minimum efficiency of 55 per cent under both the Chinese and the Indian standards. The stove from Rwanda was very close to the prescribed efficiency.
- None of the stoves and lamps qualified on account of CO concentration in smoke/ flue gas.
- The size of jet was too small in all the cases.
- All tested biogas stoves had almost a common problem of inadequate burning area.
- The position of one-time air intake was normally located at the throat, and the air intake door was too small, which could not bring sufficient amount of air, which was the main cause of high CO concentration in smoke.
- Construction of different parts of stoves, in particular the casting of burner was poor, except the samples from Lesotho and Vietnam.
- There was no permanent marking, incorporating information, such as manufacture's name, rated gas pressure, gas consumption or heat load, etc., except in case of the stove from India, in the form of a metallic plate fixed on stoves or lamps.

15.8 Comments on individual stoves

Observations made against stove of an individual country are enumerated below:

- The casting of burner from Bangladesh was extremely poor.
- The heat flow of the stove from Lesotho was too low due to the small jet and improper positioning of the primary air intake.
- The design of primary air intake and the length of pan support of the stove from Nepal were not proper.
- The crown area of stove from Vietnam was too small and the gas did not combust fully, which caused high heat flow, low efficiency and high CO content in smoke.

16. Recommendations

16.1 Improving construction of stoves

The physical measurements of critical parts of stoves and lamps should be standardized and should not vary from piece to piece. It means the manufacturers should follow standard manufacturing practices.

16.2 Improving designs of stoves

A list of problems with the stoves tested and suggestions for improving designs are given at Table 19.

Table 19 Problems with tested stoves and suggestions for improving designs of stoves

Parameter	Main problem	Recommendations for improvement
Burning area in stoves	Less in all tested stoves	Increase the burning area, i.e., the area of fuel mixing tube between throat and the flame ports
Primary air intake	Placed in the throat area	Place it at the front.
Injector jet	Too small and the burning area could not match the primary air intake.	Redesign based on correct calculation on the requirement of primary air (> 50 % of total demand for complete combustion). If possible, venturi jet is provided for proper mixing of gas and primary air.
Gas tap	Not provided in some stoves	Provide at least one gas tap for each burner.
Heat flow in Lesotho stove	Too low due to small jet	Heat flow is increased to enhance thermal efficiency.
Distance between flame port and cooking pan	Short length of pan supports interfered with flame ignition	Should neither be too short nor too long, while supporting the commonly used pan firmly

16.3 Improving design of lamp

All samples of lamps performed extremely poor. Since considerable many biogas lamps are promoted every year by SNV in many countries, concerted efforts should be made to chalk out an action plan for developing a better design of lamps. It might be desirable to collect samples of lamps, manufactured in India in 80's (which were reported to be of superior quality) and at present in China and other countries and study them from the view point of selecting better version or parts for designing a simple but efficient lamp at a cost as low as possible, without scarifying quality and performance.

16.4 Marking on the appliance and supply of an instruction sheet

It should be mandatory for manufacturers to fix a permanent marking, incorporating information, such as manufacture's name, rated gas pressure, gas consumption or heat load, etc., on each biogas appliance. An information sheet describing assembling of different parts of the appliance and method of its efficient operation and maintenance should be supplied along with the device.

16.5 Business Meet of Appliances Designers/Manufacturers/Suppliers

A Business Meet of Designers/Manufacturers/Suppliers of biogas appliances, representing the countries where SNV is operating, should be organised to discuss the already identified problems and issues and prepare an action plan for bringing in immediate improvement in the designs of both stoves and lamps.

16.6 Training of appliances manufacturers

The manufacturers of appliances, who are ready to implement the action plan proposed in paragraph 16.5, should be given training for learning and adopting a common testing methodology. For the purpose, an institute, preferably having both workshop and testing facility, should be selected for conducting the training course.

16.7 Establishment of in-house testing facility

It should be mandatory for biogas appliances manufacturers to have in-house testing facility. However, in general no manufacturing workshop in the countries where SNV is supporting the biogas programs has any testing facility. Therefore, manufacturers should be encouraged to upgrade their workshops by establishing testing facility. Financing institutions could be involved in providing loan for establishing the facility. Wherever financing institutions are not forthcoming in spite of efforts made, then SNV should consider arranging loan on a soft term for upgrading manufacturing workshops, at least one in each country, even through its present charter does not permit such arrangements. Otherwise, it would be difficult for SNV to ensure promotion of quality appliances under its program.

16.8 Preparing national standards for appliances suited to fixed dome plants

Many developing countries are promoting fixed dome plants. It was assumed that China, which is pioneer in developing fixed dome designs, has standards suited to this type of plants. However, considering high but variable gas pressure, high content of methane in biogas, etc., questions have been raised about the suitability of such standard (Kellner, 2008). Therefore, there is a need to develop specific standards for appliances suited to fixed dome plants. Each country should formulate its own standard specification after considering factors, such as cooking vessels, food habits, etc., as well. SNV could arrange expertise for drafting standard specification in consultation with local manufacturers and technical institutions.

16.9 Developing mathematical modeling for biogas appliances

Ideally, the testing methods followed at the three institutes should have given almost similar results, provided a uniform method of testing would have been used. Since different values for almost many parameters were obtained, it pointed out to the need for standardization of testing methodology. In the past also, studies on stoves conducted in Nepal and other countries have pointed out such requirements (Shreshta, 2004). The solution to this problem is to develop a mathematical model that relates the overall efficiency of an appliance to critical dimensions and also to its operating conditions. Such a model will have two advantages: it offers a means for optimizing the efficiency of the appliance and it does not rely significantly on methods of testing.

16.10 Short-term applied R&D on biogas appliances

R&D areas identified based on the test reports for short term duration (< one year) to be carried out at two or three institutions located in the countries having different cooking/lighting requirements are mentioned below:

Stoves:

- Designing jet size matching with rated heat flow at a given inlet gas pressure
- Placement of primary air intake hole (s)/regulator
- Volume of air-fuel mixing area
- Matching burning area and height of pan support with vessels common in a given area
- Developing a gas pressure regulator to suit the inlet gas pressure requirements

Lamps:

- Matching size of mantles commonly available in the market with clay nozzle
- Placement of primary air intake hole (s)/regulator
- Designing low cost reflector
- Selecting low-cost mantle cover without losing luminance
- Improving luminous efficiency

SNV has already started action in carrying out research in some of these areas (Anonymous, 2008).

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