Safety issues for clean liquid and gaseous fuels for cooking in the scope of sustainable development

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Several fuel types have been used for cooking throughout the world, ranging from solid fuels to liquid to gas. Gaseous fuels are considered cleaner because of their inherent characteristics of low pollutant formation and emissions during handling and use. Nevertheless, from the viewpoint of sustainable development, other safety properties are important, such as flammability limits, auto-ignition temperature, specific gravity, vapour pressure, toxicity and flash point. This paper discusses several aspects of cooking fuel safety, considering traditional clean fuels such as LPG, natural gas and kerosene, and non-traditional and/or renewable fuels such as DME, producer gases, biosyngas, ethanol and ethanol-gel. The main aspects are related to transport and distribution system, product poisoning, equipment and use. Gaseous fuels are the preferred solution to replace unhealthy traditional fuels. As renewable options are still under development, LPG is often considered the short-term solution to deliver modern energy on a global scale for cooking applications.

1. Introduction

Several fuel types have been used for cooking throughout the world, ranging from solid to liquid to gas. Gaseous fuels, followed by light liquid fuels, are considered the cleaner varieties because of their inherent characteristics with low pollutant formation and emissions during handling and use.

Traditionally, gaseous fuels are fossil fuels derived from petroleum or natural gas, and their usage cannot be considered sustainable in the long term.

The combustion characteristics of gaseous fuels are suitable for cooking purposes because of the ease and safety of operation and combustion control. These features have allowed for the development of high efficiency and low pollutant emission stoves. In addition, they favour ease of global distribution through either pipeline or bottles.

At the present time, natural gas, liquefied petroleum gas (LPG) and kerosene are the clean fuels favoured internationally for domestic cooking. Replacing traditional fuels reduces deforestation, protects users' health by reducing smoke and soot, and allows time for women and children to pursue education and other productive activities. Future substitutes for clean fossil fuels for domestic cooking may include biogas, biosyngas, dimethyl ether (DME), ethanol and ethanol-gel.

Table 1 shows the typical composition and characteristics of gaseous fuels and Table 2 presents the main combustion characteristics of fuels and gases dealt with in this paper.

2. Traditional clean fuels for cooking (LPG, natural gas, and kerosene)

2.1. LPG

The term "LPG" is an abbreviation of liquefied petroleum gas also known as "LP gas" or "bottled gas". An accurate term would be "LPGs" or "LP gases" since the name includes a family of light hydrocarbon compounds of varying molecular structures, the main two ingredients being propane (C_3H_8) and butane (C_4H_{10}). Commercially, LPG generally consists of a varying blend of these two gases and of unsaturated derivatives.

These hydrocarbon compounds exist in nature as gases, but are liquefied for simplicity and efficiency of storage and transportation. Several hundred volume units of vapour are condensed into a single volume unit of liquid when subjected to slight pressure or refrigeration. When depressurised before burning, the liquid expands and reverts to its natural gaseous state. It is this unique ability to be both a liquid and a gas in the same container that accounts for its efficiency in transportation, storage and use.

The history of LPG since its invention in 1912 is closely aligned with its use for cooking and lighting. Named "gasol" by its discoverer, Walter O. Snelling, this unique product has 4 times the heating capacity of coal gas and produces a brighter light than either natural gas or coal gas. Because of its high heat content, consistent temperature and cleanness, LPG began to be used as a replacement for coal and wood, the traditional cooking fuels.

Today, hundreds of millions of people throughout the world rely on LPG for cooking, because of its portability, cleanness, convenience and safety – the same reasons why it became popular nearly 100 years ago.

2.2. Natural gas

Natural gas, like petroleum and LPG, is a fossil fuel, and it can be found in underground gas fields or associated with petroleum. Its main constituent is methane. Since natural gas cannot be liquefied at atmospheric temperatures, its transport and circulation is managed through pipelines. In the United States, the first long-distance transmission of natural gas started in 1930 [EIA, 1997]. Its use extended to areas near the giant gas fields and, later, to farther regions by pipeline transportation from the fields, such as the North Sea, the Middle East, and Siberia.

Natural gas has shown a great growth in popularity in metropolitan areas of developing countries in South America, such as Argentina, Bolivia, Peru and Brazil. The market there is strong enough to ensure that the system of transportation and distribution remains profitable. In other regions, natural gas has substituted the older, local town gas manufactured from coal or from hydrocarbons. In these cases, the old distribution systems are used with small modifications.

Town gas was a mixture produced from coal gasification by means of several different conversion processes and was the first gas distributed in cities. It originated in the middle of the 18th century and was used exclusively for lighting purposes. During the 19th century, its popularity soared and remained high until the first half of the 20th century when it was gradually replaced by natural gas.

2.3. Kerosene

Presently, the familiar liquid cooking fuel, known as paraffin (e.g., in South Africa) or kerosene (e.g., in the United Kingdom), is a hydrocarbon mix, similar to aviation turbine (jet) fuel, with a primary distillation between 185 and 240ºC, placing it between petrol and diesel. The tremendous growth of commercial aviation triggered a dramatic increase of paraffin production in refineries. The marketed product is a jet fuel more or less hydrogenated to exclude impurities and reduce odour, making indoor use suitable. A similar product called "burning oil" is used in UK domestic boilers, whereas other parts of the world operate with diesel blends.

The history of paraffin or kerosene is older than that of natural gas as it belongs to the first generation of petroleum products. Burning the surface of a natural liquid product to produce light was practised in the ancient Middle East.

Table 1. Typical composition and combustion characteristics of gaseous fuels for cooking

Typical composition (% volume)	LPG	DME	Natural gas	Biogas	Biosyngas	Producer gas
H_2					51.8	14.7
CO					45.1	16.6
CO_2			0.1	45	2.7	18.4
N_2			1.4			50.6
CH_4 (methane)			91.8	55	0.4	0.3
C_2H_6 (ethane)	0.5		5.6			
C_3H_8 (propane)	34.3		0.9			
C_3H_6 (propylene)	24.4					
C_4H_{10} (butane)	28.2		0.1			
C_4H_8 (butene)	12.6					
C_2H_6O (dimethyl ether)		99.5				
Wobbe index (kJ/m^3)	69560	46198	48530	21960	17477	4990
Low calorific value (kJ/m^3)	87990	58437	37590	21850	12603	5160
Specific gravity to air	1.6	1.6	0.6	0.99	0.52	1.07
Air/gas stoichiometric (m^3/m^3)	25.5	19.1	9.9	5.2	3.4	1.1
Gas family	III	II	II	I	I	I

Table 2. Main combustion characteristics of gases and liquids of fuels for cooking

	Lower inflammability limit in air (% volume)	Upper inflammability limit in air (% volume)	Auto ignition temperature (ºC)	Specific gravity to air	Vapour pressure at 17ºC (bar)	Boiling point (ºC)	Flash point (liquid fuel) (ºC)
Methane	5.3	15.0	540	0.55		-162.3	
Ethane	3.0	12.5	515	1.04	35.0	-88.0	
Propane	2.2	9.5	450	1.53	7.7	-42.2	
Propylene	2.4	10.3	460	1.45	9.4	-48	
Butane	1.9	8.5	405	2.01	1.9	-0.6	
Butene	1.6	9.3	385	1.94		3.0	
Hydrogen	4.0	75.0	400	0.07		-252.7	
Carbon monoxide	12.5	74.0	605	0.97		-192	
DME	3.4	27.0	235	1.6	4.8	-23.7	
Ethanol	4.3	19.0	365	1.59		78	15
Methanol	7.3	36.0	385	1.11		65	16
Kerosene	0.8	5.4	250	5.0		185 to 206	40 to 55

Sources: inflammability data from [Lewis and von Elbe, 1961] and physical properties from [Perry and Chilton, 1973].

Note

The boiling point for kerosene is for "80 % recuperation". This means that the boiling point for kerosene is the temperature at which 80 % of it is evaporated.

3. Renewable fuels for cooking (producer gas, biogas, DME, and ethanol)

3.1. Producer gas

Producer gas is a combination of gases from biomass gasification, a process differing from coal gasification. Wood, agricultural wastes and charcoal are used to generate this form of gas, usually on a relatively small scale for local small-industry applications. It is a combination of hydrogen, carbon monoxide, carbon dioxide and a considerable concentration of nitrogen owing to the air used as a gasification agent. Because of these characteristics, it has a low heating value and its storage is impracticable. Thus, it must be consumed as soon as it is generated, a complication for domestic use. Nevertheless, community and institutional gasifier-cooking systems have been developed in India and China [Bhattacharya and Salam, 2002].

A further evolution from producer gas is biosyngas [Conti and Ostan, 2001], which has similar characteristics to town gas, but comes from renewable feedstock and is a concept being developed for villages or small towns.

3.2. Biogas

Biogas results from the anaerobic digestion of organic wastes (sewage, manure, organic matter). It is composed of methane and carbon dioxide, including traces of sulphurous and other gases. Bio-digesters have been built and exploited in rural areas of India, China and Nepal [Bajgain and ter Heegde, 2004]. China has roughly 11 million domestic bio-digesters [Jingming, 2003] and India around 2.9 million [Bhattacharya and Salam, 2002]. Bio-digesters permit storage capacity, allowing for equilibrium between production and demand for consumption. Biogas is an authentic sustainable fuel because it makes use of organic wastes.

3.3. DME

Dimethyl ether (CH_3-O-CH_3) is a clear liquid which boils at -25ºC, similar to LPG. Other properties make it comparable to propane and butane. Therefore, the storage and handling technologies of LPG are applicable to DME. DME is currently employed in spray paints, agricultural chemicals and cosmetics, and also as a propellant alternative to freons.

Creating DME from stranded deposits of natural gas is an attractive and economical way to liquefy natural gas for simplification of transport and storage. Japan is particularly aggressive in its DME research and pilot plants are already in production. Moreover, China is developing a process to make DME from coal, which would turn its large natural coal resources into an easily transportable and cleaner fuel. It plans to build an 830,000 t/year DME factory, with DME cost much lower than that of synthetic diesel (Fischer-Tropsch diesel) on an equal energy basis [Longbao et al., 2002].

DME has been proposed as an alternative to liquefied natural gas (LNG), which has to be refrigerated at cryogenic temperatures for liquefaction, or as a substitute to diesel fuel owing to its excellent performance in diesel engines with lower particulate matter emissions [Kikkawa and Aoki, 1998].

DME synthesis from biomass has been tested on a laboratory scale and seems promising at medium term [Jie and Tiejun, 2003]. For additional discussion of DME, see Han et al. [2004] and Larson and Yang [2004] (both in this issue).

3.4. Ethanol and ethanol-gel

Ethanol, which is rare in domestic use, has the attractive quality of being derived from renewable sources (bio-ethanol). It is produced by the fermentation of saccharose-rich juices with posterior distillation. The feedstock may be sugar cane in tropical countries or sugar beet in others.

Ethanol is available in countries which are important sugar-cane producers, such as Brazil. Anhydrous ethanol is added to automotive petrol up to a maximum of 25 %. Pure hydrated ethanol is used by a significant proportion of Brazil's cars. Furthermore, ethanol is employed in domestic detergents and sanitizers.

In Brazil, hydrated ethanol was bottled in plastic containers (0.5-1.0 litre) for household consumption. Owing to the high number of domestic burn accidents caused from misuse, a law enforced its substitution by ethanol-gel. Ethanol-gel is a mixture of ethanol and a thickener additive (carbopol or carboxymethylcellulose) that alters it to a colloid with high viscosity, increasing its safety during handling.

4. Safety properties of fuels

The inherent hazards from cooking with these liquid and gaseous fuels are burns, fires, explosions, poisoning by breathing or ingestion, and other related risks. Safety issues related to their domestic application are therefore intrinsically associated with their physical and chemical properties. The cooking fuels considered are classified as:

- liquefied gases (LPG, DME);
- distributed and manufactured gases (natural gas, town gas, biogas, biosyngas);
- liquid fuels (kerosene, ethanol, methanol); and
- liquid-gel fuels (ethanol-gel).

The main properties related to safety issues are the following.

- Lower and upper combustible limits, which denote the atmospheric gas concentration range where ignition and combustion are possible.
- Auto-ignition temperature – the minimum necessary temperature for starting atmospheric combustion at a stoichiometric ratio.
- Specific gravity to air – the ratio between the gas density and the air density.
- Vapour pressure – the storage pressure for liquefied gases.
- Wobbe index – the chemical energy that will flow through an orifice with a given pressure drop, calculated by dividing the heating value of the fuel by the square root of specific gravity. This property is used to evaluate the gas inter-changeability and flame stability for aerated burners. Extinguishing the flames on stoves without shutting off the gas produces a gas leak that increases fire and explosion risk due to indoor air-gas mixture formation.
- Toxicity – concerns gas aspiration or liquid ingestion.
- Flash point – the minimum temperature at which there is a sufficient concentration of vapour formation above the liquid surface to start a momentary flame.

5. Safety issues regarding clean fuels for cooking

5.1. Transport and distribution system

5.1.1. Liquefied gases

Safety and risk issues for clean hydrocarbon fuels have to be managed at several levels beginning with the supply and distribution system. LPG requires a specific distribution system apart from solid or other liquid fuels because it is stored and transported in pressure vessels. Although the source of LPG supply may be the same refinery or terminal from which other products are distributed, the equipment, storage tanks, trucks, rail wagons and the appliances themselves are uniquely designed for LPG. This ensures that equipment cannot be modified to accept other fuels, thus providing an additional level of safety and control.

LPG is readily portable, meaning it can be stored and transported virtually anywhere in containers of various sizes. Throughout the developing world, LPG is distributed in cylinders or "bottles" ranging from 5 to 15 kg. Generally, they are filled at dedicated and controlled facilities where a strict safety policy is enforced, allowing only legal cylinders to be used and filled to the proper level. These cylinders are typically owned by the fuel supplier, but in some countries the customer is the owner. In the latter case, it is difficult to enforce safety practices since the cylinder may not come back to the expert facility for inspection and repair if needed.

Unethical and unlicensed operators have a tendency to ignore safety standards and practices. Caution must be taken to ensure the removal and destruction of damaged or unusable cylinders. Some unscrupulous operators have been known to take parts of unusable cylinders, weld them together and put a cylinder back in service. Such practices are not only violations of international standards, but also a definite danger to people and property.

Care must be taken to ensure that containers designed for only butane are not filled with propane because of the higher vapour pressure of propane. On the other hand, propane containers may be used to contain butane. Cylinders properly manufactured have a data plate that identifies the design parameters.

Unlike liquid fuels that can be transported and stored in non-dedicated containers, LPG equipment is designed solely for LPG usage. This may come at an economic penalty for those who wish to transport several fuels in a common truck or store various fuels in a non-dedicated container. However, dedicated equipment prevents deliberate or inadvertent mixing of fuels, the results of which can be dangerous.

The greatest risk at distribution (or refill) facilities is fire. An unintended release of LPG that finds its way to an ignition source can result in a severe blaze, leading to property damage and/or bodily harm, and, rarely but possibly, explosion. Some jurisdictions now favour mounding of tanks or installing them underground, avoiding storage explosion risk. The simple practice of prohibiting any kind of flame, cigarette lighter or flammable material from a facility is significant in precluding the danger of fire.

Sound design and construction that respect international regulations, safe operating procedures, trained operators, and a fire suppression system are essential for a sufficiently safe refill/distribution facility. Another factor is the enforcement of applicable policies and laws by local authorities, including a permit to operate the facility. Shortage of funds, inadequate regulations, lack of trained inspectors and corruption are common problems in many countries that compromise an effective risk management and safety programme.

DME is not commonly used as a cooking fuel, even if it is currently being experimented with in China on a small scale. LPG safety considerations and, with small modifications, distribution and storage systems can be applied to DME because of similar handling properties.

5.1.2. Gases distributed by pipelines

Gases not liquefiable at ambient temperature must be transported and distributed by pipelines. This technique is well established and began in the middle of the 18th century with the transportation of town gas used for lighting and heating. These days, natural gas is dispersed to homes and commercial consumers throughout the world.

Safety issues related to distribution are the supplier's responsibility. Generally private- or state-owned, they receive a concession for gas distribution and commercialization from the government. This is a monopolistic activity, like electricity distribution, regulated by law and technical standards for quality and safety guarantees. However, the effective safety depends on the capacity of the supervisory department. The supplier's responsibility ceases, in general, at the consumer's "gate". The piping from this "gate" to the consumption points becomes the consumer's responsibility. Pipes made of durable materials (copper, carbon steel) demand little or no maintenance. Attention must be paid to old installations, hidden in walls or below the ground, limiting visual access for inspection.

The safety records of natural gas are notable where it has been used for several years or where it has replaced a town gas used by regular consumers. Special care must be taken in developing countries, where the supply has begun recently. As an example, the Bangladeshi government, supplying natural gas to new users, had to warn them not to keep the gas burning throughout the night, increasing the risk of leakage. The habit of Bangladeshi citizens was to have water boiling throughout the day *and* night, and since the monthly fee was a flat rate, many users found it easier to keep the gas burning continuously.

As a future alternative to natural gas, synthetic gases made from biomass are practical choices since the same facilities can be used with and the same considerations applied to biosyngases as in the case of natural gas.

5.1.3. Liquid fuels and liquid-gel fuels

Kerosene is easy to store and transport because it does not require the use of specific tools, making it uncomplicated to store in any container and marketable in very small quantities. This flexibility has its benefits, but inconveniences as well, the greatest being the risk of mixing with other hydrocarbons. With a lighter hydrocarbon there could be a risk of explosion when the product is heated for combustion (frequent accidents are reported in Nigeria). With a heavier hydrocarbon, there is poor combustion with production of smoke and tar. The frequent cause of dangerous mixing is not the lack of caution (even if a very hazardous mix of petrol and kerosene can occur from time to time), but fraud. Products for domestic use enjoy generally a much lower duty rate than road transport fuels, in many countries encouraging smuggling, which increases the risks dramatically.

Hydrated ethanol is distributed in small containers (0.5-5 litres) made from plastic (polyethylene is most common). Owing to the containers' flexibility and the ease of handling, bottled ethanol has been the cause of several domestic accidents. In Brazil, ethanol is the main cause of domestic burns; nevertheless, it remains an attractive fuel for cooking, though not normally used for that purpose.

Ethanol-gel can be distributed in the same form (plastic bottles) or by other container types. Its high viscosity makes it difficult to completely empty the container and a few non-serious accidents have been caused by cutting or destruction of the bottles. When spilled, ethanol-gel does not spread like a liquid.

5.1.4. Illegal practices in distribution

Since cylinders are expensive to purchase, pirate operators tend to steal them. Needless to mention, they overlook the inspection for damage or certification of the cylinders, over-fill or under-fill them, put abandoned cylinders back in operation, and lack the skills to operate trucks and facilities safely.

The tax on domestic (cooking) gases is low in many countries to encourage their use in preference to traditional fuels. But, because LPG is an excellent automotive fuel and considering the higher taxes on fuels for automotive use, the fear is that attempts will be made to use a cooking gas cylinder in a vehicle, or transfer the fuel from a cooking gas cylinder to that of a vehicle. This is a dangerous practice and also an illegal one because it cheats the government of its rightful tax revenue.

Using subsidized kerosene as an automotive fuel is also an illegal practice, but there are no specific risks during a transfer. If kerosene is used in a petrol engine it can cause severe damage to the engine.

5.2. Lighting, extinction, flame stability and interchangeability of gases

Unlike biomass fuels that require time to reach an acceptable cooking temperature, LPGs and other gases are instantaneously hot. When not in use, the fuel supply is simply turned off, conserving precious supplies and eliminating the danger of hot glowing coals, a source of many burn accidents mainly suffered by children.

Flame stability is an important characteristic for fuel gases. Burners for stoves are usually pre-aerated: combustible mixture is formed in the space preceding the point where the flame occurs. Flame stability is related to flame speed (Weaver flame speed factor) and its specific energy content (Wobbe index). Gas burners must be designed to accommodate exclusive gas characteristics. If the flame speed is high, the flame will become too elevated and extinguish. If the speed is low, the flame returns to the aeration channel and light-back occurs, also extinguishing the flame. In conditions where there is not sufficient air, an incomplete combustion starts as a yellow tip burning on hydrocarbon gases. For the same burner, fuel gases are interchangeable within conditions determined by their characteristics (Wobbe index and Weaver index) and classified in groups (gas families). Gases from the first family are manufactured gases with high carbon monoxide and hydrogen content. Gases from the second family are the several natural gas compositions, and gases from the third family are liquefied gases from petroleum.

As DME utilization on aerated burners is recent, there is scarce data about its characteristics with regard to flame stability and interchangeability.

Kerosene, ethanol and ethanol-gel are easier to ignite than biomass fuels and can quickly produce an acceptable cooking temperature. By cutting off access to air, a kerosene fire can be extinguished quickly and the cooking surface will not remain hot for very long.

Kerosene and others liquid fuels are in an intermediate position between instant on-off fuel gases and traditional solid fuels.

5.3. Flammability limits

Three things are necessary for combustion: oxygen, fuel, and a source of ignition. The ratio of fuel to air (flammability range) in order to have a combustible mixture with LPG is very narrow, meaning too much or too little fuel mixed with air will not support combustion.

Considering typical LPG compositions (propane and butane), its flammability range is 2-9.5 % by volume in air. Natural gas and biogas range from 5 to 15 % and DME from 3.4 to 27 %. Manufactured gases such as biosyngas represent the largest flammability range, 4-75 % by volume in air, caused by the presence of hydrogen and carbon monoxide. Besides the flammability range, the lower limit is a crucial factor indicating the concentration where the risk of fire and explosion are possible.

LPG has a lower flammability risk than natural gas. LPG's greater density slows its capacity to disperse quickly and it therefore has a lower risk compared to natural gas. High-density LPG (also DME) leakages have a tendency to accumulate closer to the ground, whereas the lower-density natural gas rises. This LPG characteristic is particularly hazardous for underground piping inside buildings.

The auto-ignition temperature for most hydrocarbon gases ranges from 400 to 500ºC. The few exceptions are methane's higher temperature of 540ºC, DME's reported low of 235ºC [Chen et al., 2000, Longbao et al., 2002], and kerosene vapours at 250ºC. Evaluating the fire risk with hot surfaces is very important in case of leakage.

Kerosene vapours have a narrow range and ignite at a low concentration, 0.8-5.4 % volume in air, compared to ethanol, whose range is 4.3-19 %. Kerosene is also high in density, thus preventing quick dispersion.

The potential of vapour generation from liquid fuels is evaluated from their flash point. The flash point of ethanol is 15ºC and it has a higher capacity to generate vapour than kerosene. The flash point of kerosene is estimated at 40-50ºC, but it is a mixture of several hydrocarbons and its flash point may vary beyond its typical limits. Flash point is controlled by formulation in the refineries and strongly regulated to improve safety for aeronautical proposes [Shepherd et al., 2000].

5.4. Odorization

In its normal state, LPG is odourless. Odorants are added to provide ample notice to correct any problem before a leak becomes hazardous. The odorants are distinct, strong-smelling chemical compounds selected on the basis of human sensitivity to their scent. Very minute quantities are needed for detection. Normally, the odour is injected at or near the source of supply so as to taint the entire distribution chain. Odourless LPG is employed in selected specialized industrial and commercial applications, but should never be accessible to the public.

Paraffin has an odour, but owing to its common practice of storage in open containers this odour is always present and is not an alert to a potential hazard.

5.5. Health issues

Any source of energy in a successful sustainable development scheme must satisfy the basic requirements of being environmentally friendly, affordable, promoting economic growth, and being socially acceptable and accessible to a large part of the population. The importance of cooking fuels because of their intrinsic importance in sustaining livelihood itself requires an analysis of their role in the sustainability criteria.

The health issue is a high priority and is well documented in many studies. Using clean cooking fuels can dramatically lead to improved health conditions, particularly for women, small children and senior citizens. Traditional solid fuels emit a large number of pollutants that lead to premature births and low birth-weight of children, acute respiratory infections, chronic lung disease, heart disease, and eye conditions. A child is two to three times more prone to infection if exposed to smoke in the home. Children under five account for 56 % of total deaths from indoor air pollution. Households relying on wood, dung and crop waste are especially vulnerable [WHO, 2002].

Compared to solid fuels, the pollutant emissions from gaseous fuels are extraordinarily lower. LPG and natural gas are low-polluting, and laboratory tests have shown emissions still lower for DME [Frye et al., 1999]. Light liquid fuels, mainly the oxygenated fuels such as ethanol, also burn with low emissions comparable to those from gaseous fuels.

5.6. Product poisoning

5.6.1. Gases

LPG and natural gas are non-toxic. The inhalation of small concentrations during short periods will not produce adverse effects on humans. Exposure to higher concentrations in short intervals, while undesirable, is still not dangerous to life. LPG is classified as an asphyxiate, meaning it will displace oxygen in very confined spaces. Concentrations of 10 % vapour in air during an exposure of 2 minutes can produce vertigo or dizziness. However, such an occurrence is unlikely since it would necessitate a large release in a confined space. LPG is not readily accessible since it is stored under pressure in sealed containers. DME's toxicity is very low and comparable to that of LPG.

Having methane and carbon dioxide as main components in its composition, biogas is not toxic. Biosyngas however contains carbon monoxide and is very toxic.

Carbon monoxide poisoning is the major cause of death in residential and coal-mine fires [De Nevers, 1995]. If a person does not die of such exposure, the health effects are reversible. Carbon monoxide causes harm by binding with the haemoglobin in the blood, forming carboxyhaemoglobin (COHb). Carbon monoxide attaches to haemoglobin roughly 220 times more strongly than oxygen, so small concentrations in the air can lead to significant blood concentrations of COHb, impeding the transport of oxygen by haemoglobin in the blood, a vital function. When COHb takes up 70 % of the amount of haemoglobin, it becomes lethal. In most standards, the TLV (threshold limit value) for CO permanent exposure is 25 ppm or less.

5.6.2. Paraffin

Kerosene stored in a kitchen or in any kind of container can be hazardous. While incidents of inhalation are rare, ingestion by children is a serious issue. A report to the Paraffin Safety Association of South Africa in 2001 [Lloyd, 2001] concluded that in the previous year:

- at least 143,000 children drank paraffin;
- at least 55,000 children contracted pneumonia after drinking paraffin;
- at least 4,000 children died from paraffin-induced chemical pneumonia;
- there were at least 46,000 paraffin-related fires and 50,000 burns;
- 31,000 (63 %) of these burns were the result of paraffin stoves exploding; and
- fire records showed at least 100,000 homes were destroyed as a result of paraffin stoves exploding.

For LPG in a two-year data comparison, there were only 6 domestic injuries and 3 fatalities in a single camping accident. The role of LPG in the camping accident was doubtful. While the number of households in South Africa using LPG is only 15 % of the total of paraffin users, relative safety of LPG is clear from the fact that the incidents with LPG were dramatically fewer.

5.6.3. Other liquid fuels

Regarding other liquid fuels, two specific potential hazards have to be mentioned.

1. Ethanol is very often drunk as an alcoholic beverage by people who are not aware that it can be dangerous at high concentrations. Methanol is even more dangerous as it can cause serious liver poisoning (Indian experience) and even small quantities can cause permanent blindness.
2. Because these products are soluble in water, any spillage can cause contamination of soils or aquifers.

6. Equipment and use

6.1. LPG cooking

A typical cooking system consists of a cylinder made of steel, a pressure regulator, a hose connecting the regulator to a burner and the burner. Whether it is a multi-tonne storage vessel at a supply depot, a tank on a rail wagon, a truck or a small 1-kg cylinder, the materials and their fabrication methods are the same. Although steel is the most common material used in constructing cylinders and containers, lighter materials for cylinders such as aluminium, stainless steel and composite materials are now being introduced in some developed countries. Regulators that control the flow of gas to the burner are simple devices with a long life, over 20 years if properly maintained. The low-pressure hose connecting the regulator to the burner is tested to a pressure far exceeding what it will be exposed to during normal service. Burners are made from a variety of materials including cast iron, tin and aluminium. All the elements in a cooking system will provide long life with very little special care. The hose is not an expensive component of the system and the component most likely to suffer abuse since it is not made of metal. The hose when made of rubber should be replaced every 3 years or so depending on its condition.

The major leakage risk occurs in the connection between the connector and the hose, which, if not tight enough, can allow gas leakage even if gas pressure is low. Attention must be paid to proper assembly and position of the plastic or rubber hoses, because if they are close to oven walls or fire, there is a possibility of intense heat which can soften the hose, and consequently cause leakage.

From the most basic cooking systems to the most sophisticated, the essential elements are the same. One variation has the burner clamped directly to the regulator-cylinder, thereby making a tight, compact, easily portable cooking system. Burners generally are equipped with an air adjustment in order to provide the correct fuel-air mixture that gives a bright blue flame. Users need to be shown this adjustment.

The safety elements of which the customer must be made aware are not numerous but very important. They include making sure there are no gas leaks (easy to notice from the odour) anywhere in the system, keeping the cylinder upright since the burner uses LPG vapour from the top of the cylinder, using only cylinders that are properly tested and filled, not exposing the cylinder to a hot surface or fire and being mindful that the burner may be hot for a time after the fuel is turned off.

A liquid release from a container will “freeze-burn” skin on contact due to the rapid absorption of heat by the liquid as it vaporises.

6.2. Kerosene cooking

Cooking with kerosene generally needs a “vaporising cooker” which produces kerosene vapour that maintains the combustion process. These appliances are often produced locally; authorities must enforce the necessary quality controls to prevent domestic accidents.

Under normal circumstances and usage a liquid cooking fuel such as kerosene (with a flash point of approximately 40ºC and a self-ignition temperature of 250ºC) does not present a specific storage and usage risk, except when polluted, as mentioned before. It produces a limited quantity of vapour which will catch fire only if ignited when its concentration in the surrounding atmosphere is between 1 and 6 %.

The majority of fires appear not to be caused by a poor design of paraffin appliances. The fact is that when the fuel container is being refilled, because of the fuel specification being at a very low flash point, it is easily and very quickly flammable.

Education should therefore focus on adapted and dedicated storage means to prevent product mix, cleanness (also needed for the burners), and absence of excessive heat, flames or sparks. As with all liquid hydrocarbons, contact with skin or eyes can cause irritation.

Stoves for ethanol and ethanol-gel are not common, and the popularity of these fuels for cooking is low, although they are under development [Utria, 2004]. Burners for ethanol-gel are simple, open vessels for placing an amount of gel, with suitable apertures for air combustion control. An interesting programme for firewood and charcoal replacement by ethanol-gel for cooking is being implemented in Malawi [Wynne-Jones, 2003] and has shown good results.

7. Conclusions

Gaseous fuels such as LPG and natural gas have been proven through international, long-term experience to be safe fuels for cooking. If handled properly kerosene is also safe, but not comparable to gaseous fuels. They have good properties for storage, handling and utilisation, but these traditional clean fuels are fossil fuels. Renewable fuels for long-term sustainable development still have limitations or are under technical development.

Biogas is a good option for cooking: safe, non-toxic, and derived from a renewable source. Yet it remains infeasible for urban and metropolitan regions. Nevertheless, it has been proven to be a sustainable cooking fuel, according to the experiences of Chinese and Indian users.

DME is a promising fuel, and could be developed through synthesis routes from biomass.

Biosyngas is an attractive renewable gaseous fuel, because its technical basis is well known and further development is feasible. However, it presents a safety concern due to the presence of carbon monoxide in its composition. Nevertheless, town gas, with the same property, was used for almost a century in the past.

Ethanol-gel is another attractive fuel for cooking falling in the scope of sustainable development. It is safe, with low-polluting emissions, and can be made from several renewable feedstocks. It is not as versatile as gaseous fuels, because burners and equipment need to be improved, yet Malawi's experience with using it for cooking is encouraging.

Gaseous fuels are the preferred solution to replace unhealthy traditional fuels. LPG is available everywhere. As renewable options are still under development, it is often considered the short-term solution to deliver modern energy on a global scale. ■

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