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Domestic Air Pollution

—The Effect Of Wood Smoke On The Health Of Women

ATMOSPHERIC pollution has for long been regarded as probably the least important of all the environmental problems in the country, concentrated mainly in the major cities and industrial towns. But latest evidence shows that air pollution within homes may be an acute problem, an underlying cause of millions of deaths every year. The burning of cooking fuel envelops the indoor environment with heavy smoke, and women who have to do all the cooking may be daily exposed to more pollutants than even industrial workers in extremely polluted environments on extremely polluted days. Thus, women are being affected at every end of the cooking cycle : as firewood becomes scarce they have to put in more energy to collect fuel and then they have to face the dangers of wood smoke every day.

Reducing indoor air pollution in poor homes is, thus, a most urgent environmental task today, a subject that should be of concern not only to environmentalists but also to health workers.

Domestic Pollution

For thousands of years, people have cooked using firewood and cowdung. Even today, over 90 percent of households use wood, dung and crop residues as fuels. Smokefilled huts are a common sight across the countryside. During winter, when a temperature inversion prevents the smoke from rising, entire villages look as if they have been teargassed.

In developed countries, most people have given up cooking on wood or other renewable biomass resources like dung and crop wastes.

But since the late 1950s, partly because of environmental concerns and partly because of the rising cost of conventional fossil fuels, there has been a resurgence of interest in the use of firewood, especially for heating homes. In the US, the use of wood had been falling since the turn of the century but began to rise in the mid 1960s at a rate of about one percent per year and between 1975 and 1981, after, the oil crisis, it grew at an annual average of almost seven percent.

With growing use of wood, environment protection agencies in developed countries commissioned a number of studies to assess the impact of firewood use on air pollution. These studies revealed that biomass fuels, particularly in small scale combustion as in residential stoves, emit several important pollutants in high quantities compared to gas, oil, and even coal—the most polluting fossil fuel. As a result, many communities are now thinking of limiting firewood use. The Tennessee Valley Authority in the US, for example, which had subsidised wood fired stoves, has announced a density limit for stoves in its region of 240 per square kilometre. Parts of New Zealand and Europe are facing similar options.

Life long exosure to pulluted air

Estimates have shown that firewood use per unit area is highest in semiurban areas in the US. In such areas, it has become necessary not only to limit the introduction of new stoves but also to mandate the use of specially designed, cleaner burning stoves or, perhaps, even the catalytic converters newly developed for wood fired stoves. Using the same principle used for emission control in cars, a company in the US has developed catalytic converters which can be used in a high emission wood stove. The device catalytically oxidises the products of incomplete combustion and not only reduces emission but also increases energy availability. In a number of countries, scientists and environment protection agencies are also working to develop emission efficiency standards for woodfired stoves.

The concern in developed countries is generally about outdoor air quality, that is, general air pollution. Nearly all residential stoves are designed for space heating in the house, not for cooking, and they all incorporate a system that takes waste gases outside the house. Studies show that even then, the air quality within homes can be adversely affected by woodfired heating stoves.

Smoke In Houses

But what about homes in a country like India where cooking is commonly done on open and inefficient *chulhas* with few arrangements to take the smoke out of the house ? "When compared to the thousands of person years of effort and billions of dollars that have gone into studying and attempting to relieve the air pollution problems of developed countries and cities everywhere (including the Third World), the miniscule efforts so far expended to understand this problem faced by cooks, the second largest occupation in the world (next only to agriculture), is an example of how rural women in developing countries are forgotten... No major group is lower on the global totem pole", say Jamuna Ramakrishna and Kirk Smith of the East-West Centre at Hawaii, in a paper on smoke from cooking fires.

Recognising this major gap, Kirk Smith, A.L. Aggarwal from the National Institute of Occupational Health (N1OH) Ahmedabad and R.M. Dave of the Jyoti Solar Energy Institute at Vallabh Vidyalaya, decided to carry out a pilot study in four villages of Gujarat. The study was carried out in late 1981 in 36 households in Anand district, about 90 kilometres south of Ahmedabad. The woman cook in each household was asked to wear a sophisticated air sampler which was clamped to the collar, so that the measurement device could move around with the cook and measure her actual exposure. Exposures to two major pollutants of wood smoke, total suspended particulates (TSP) and benzo (a) pyrene (BaP) were measured.

The world's worst air pollution problem'could be the wood-smoke inhaled by poor rural women while cooking. A ton of particulates from household woodstoves may actually lead to more than 500 times the human exposure than a ton of particulates from a coalfired power station.

Shocking Results

The results were shocking. The average exposure of women to TSP in their cooking period ranged from 1,110 to as high as 56,600 and averaged about 7,000 micrograms per cubic metre (μg/cum), as compared to 260 μg/cum (for 24 hours) recommended in the US and 120 μmg/cum to 150 μmg/cum recommended by WHO. The proposed eight hour Indian standard for industrial areas is 500 μg/cum and 0.1 μg/cum for sensitive areas. Concentrations of TSP are less relevant than concentrations of particles which have sizes that can be inhaled — less than three millionths of a metre. Unfortunately, biomass smoke is nearly all respirable.

The infamous London smog episode of 1954, which resulted in an 80 percent increase in mortality for a few days, mainly among the already ill, and is regarded as, one of the worst air pollution episodes, was caused by a TSP level that was similar to those experienced daily in the Gujarat kitchens. But it must be pointed out that smog was not caused by exactly the same set of pollutants and the exposure remained continuously high for several days. In the rural kitchens of Gujarat, the exposure remained high for only the cooking period, about three hours or 10 percent of the day. But in several parts of the country, daily cooking periods are as high as six hours, or 20 percent of the day. And there is no doubt that women are being routinely exposed to levels that are tens of times higher than recommended limits.

Measurement of BaP was equally shocking; an average of 3.850 nanograms per cubic metre (ng/cum). BaP has been suggested as a carcinogen in cigarette smoke. The average exposures in three hours in Gujarati homes were equivalent to smoking roughly 20 packs of cigarettes per day in terms of BaP (20 nanograms per cigarette). There are no national standards for BaP in any country. But the USSR has proposed an annual average of one ng/cum, which corresponds to an hourly average of about six ng/cum. The production of compounds like BaP is directly related to the size of the volatile fraction in the fuel. Unfortunately, in most biomass fuels, the volatile fraction is 60 percent to 80 percent of the fuel.

These estimates show that both the doses and concentrations being experienced in village homes burning biomass fuels are extremely high by global standards. They show that cooks receive a larger total dose than a resident of the dirtiest urban environment, and receive a much higher dose than the WHO's recommended level or any

Women's workplace—the ill ventilated kitchen

national public standard. Hardly any industrial worker would receive BaP doses approaching the levels found in the Gujarat study.

A number of factors make the level of exposure to pollutants worse. Dwellings in villages are small and badly ventilated. But in one of the Gujarat households, when the holes in the roof were closed, as is done regularly in monsoon conditions, ventilation was so reduced that it became impossible for the researchers to remain in the kitchen for more than a few seconds because of the discomfort caused by heavy smoke. The woman cook, however, stated that such conditions were normal during the monsoon. The exposures increased manifold and were among the highest recorded anywhere in the world.

Many households also had stoves with more than one mouth. Two mouths are used when a meal has to be prepared quickly or cooked for a larger number of persons. When a woman cooked on a stove with two mouths, exposures to TSP approximately doubled over one mouth conditions. Exposures were found to be smaller but still high even in the room, adjacent to the kitchen. In other words even the noncooking members of the family were being exposed to high levels of pollutants.

Studies conducted by the NIOH in 16 urban households in Ahmedabad using biomass fuels have also shown high levels of TSP and BaP. Concentrations increased when dung was added to or used instead of wood. TSP ranged from 4,700 µg/cum to 58,600 µg/cum and BaP up to 26,000 µg/cum.

Climate will also play an important role in increasing exposures. During the winter, and especially up in the mountains, wood is not just burnt for cooking but also for space heating. In the hills, space heating is done in small, closed houses with poor ventilation to keep the heat in. In such situations, exposure to wood smoke would be very high and would add to the wood smoke exposure for cooking.

Daily exposure to participates in Gujarat villages (milligrams per hour per cubic metre of air breathed in)

	Cooks	others
Dry season	19	6.0
Monsoon	160	3.0

Source: Kirk Smith, East West Centre

Thus, twice a year, concentrations are even higher than at other times. One is during winter, when ground level inversions are common in north India and the other during the monsoon, when whatever openings that might exist in the ceiling are closed.

Health of Women

What does this mean for the health of women who cook? The most powerful evidence for the ill effects of wood smoke comes from a survey of a heart disease called cor pulmonale, in which the right lower chamber of the heart enlarges and fails because of a disorder in the lungs. The survey was carried out over a period of 15 years on hospital patients in Delhi.

It found that there was a surprising similarity in the incidence of cor pulmonale between men and women, even though 75 percent of men were smokers of tobacco as compared to 10 percent of women.

Cor pulmonale in developed Countries has generally followed smoking patterns, being more in men. In addition, the age of onset of cor pulmonale in Delhi was much lower for women. Bronchitis and emphysema—abnormal distension of the lungs with air—were the main lung diseases diagnosed in both sexes.

Nearly all the women were from the lowest income group. While all the women patients cooked, only seven percent of the men claimed that they cooked. The cooking fuels used were mainly of dung (63 percent), wood (25 percent) and coal (12 percent).

The authors, Dr S. Padmavati and Dr S. Arora concluded : "Cigarette smoking is prevalent all over India and must be a contributory cause of bronchitis in men, but not in women, as only 10 percent of them smoke cigarettes. The women are, however, exposed to smoky primitive fireplaces from childhood. They gave a shorter history of cough and expectoration (coughing up fluid from lungs and air passages) : the onset of cor pulmonale was 10 to 15 years earlier and they showed more severe congestive heart failure, greater cardiac {heart) enlargements and greater derangement of pulmonary (lung) function with a severe loss of exercise tolerance. From this study, it appears that in Delhi, domestic air pollution is probably the cause of the higher prevalence of cor pulmonale in women than in men and the early exposure of the younger age of onset."

Padmavati and Arora argued that the lower incidence of cor pulmonale in south India as compared to Delhi may be due to generally better ventilated cooking areas.

The Gujarat study notes that women in the four villages studied had begun to learn cooking at the average age of 13. Many younger girls would get exposed to smoke, sitting by their mother. In Ahmedabad, another study of the incidence of cough, cough with expectoration, dyspnoea (difficulty in breathing) and lung abnormalities, found a statistically higher incidence among women cooking with smoky fuels.

Blowing on the hot ashes to induce fire

Studies in Nepal have shown a strong association of domestic smoke with chronic bronchitis. A survey was carried out in Jumla, a cold, remote mountain district at 2,300 metres, where climate and housing conditions are such that indoor smoke levels are noticeably higher than those in households of the midhill regions. The smoke inside the houses is concentrated enough to cause the skin and clothes of the inhabitants to become black with soot. A distressingly high incidence of acute respiratory infection (ARI) was found and was the most important cause of mortality and morbidity among infants below one year in age. Total infant mortality was about 490 per thousand and of these about 333 were due to ARI. Such mortality rates are among the world's highest and it is not difficult to believe that the high prevalence of infant and childhood ARI is due partially to the irritation caused by such indoor, smoke filled conditions. Such conditions could also prevail in Indian Himalayan villages.

Though biomass smoke is a complicated mixture of thousands of pollutants, and its impact may be more than the sum of the impact of individual pollutants, indirect evidence of the ill effects of smoke can also be gathered from studies that have been done on individual pollutants. Other than particulates and compounds like BaP, two major pollutants in biomass smoke are carbon monoxide (CO) and formaldehyde (HCHO).

Anaemic Women

Carbon monoxide is a colourless and odourless gas which is highly toxic if inhaled in sufficient quantities. Haemoglobin, the oxygen carrying substance in blood, has a much greater affinity for carbon monoxide than it has for oxygen : together they form a stable compound, carboxyhaemoglobin (HbCO), that decreases the amount of uncombined haemoglobin available for oxygen transport. If HbCO levels become high enough, coma and death can occur. It is generally believed that five percent HbCO is an appropriate upper limit for avoiding detrimental acute effects in a large population.

Oxygen deprivation at altitude acts on the body in a similar manner as increasing HbCO. For instance, if someone is at sea level, 100 ppm CO (equal to about 11 percent to 13 percent) is equivalent to being at about 3,750 metres. Studies in Guatemala show that women cooks living in villages at higher attitudes, faced with the same concentration of CO, are affected much more and have higher levels of HbCO. The impact of nearly continuous but lower exposure or daily but short term intermediate exposure to CO is difficult to assess accurately. Dizziness, headaches, nausea and a feeling of weakness can accompany moderate short term exposure, but it is not clear what, if any, are the long term effects.

There is a growing body of evidence that points to a strong link between chronic CO exposures and both heart disease and impaired foetal development. Recent evidence points to a strong association of CO with heart diseases long attributed to other combustion products of cigarettes. While CO has not itself been found to be carcinogenic, there is concern that it may act to increase the carcinogenic effects of other air pollutants by inhibiting the ability of the lungs to clear themselves.

Any condition which results in reducing the blood's capability to carry oxygen to the tissues, like anaemia (a condition in which red blood cells are reduced in number or are deficient in haemoglobin, their oxygen carrying pigment), will also make a person more susceptible to carbon monoxide toxicity. This is particularly bad for Indian women who are anaemic in large numbers. It is estimated that in India 40 percent to 60 percent of pre school children, 25 percent to 30 percent of women in reproductive age and almost 50 percent of pregnant women in third trimester (more than 24 weeks of pregnancy) are anaemic. Chronic lung diseases will further reduce the capability of the blood to rid itself of carbon monoxide during periods of low or no exposure.

There are several factors that make women particularly susceptible to CO exposure. Women generally have less haemoglobin reserve than men, which makes them more prone to anaemia, and also makes them more vulnerable to lower doses of CO than men. During pregnancy, there is additional demand on haemoglobin, further lowering their reserves and making them more sensitive to CO. This exposure can also affect the unborn child, leading to reduced birth weight and increased perinatal death rates (that is, deaths at birth or in first week of life). A 1977 study of birth weights in Los Angeles reported a significantly negative impact of air pollution of which CO was a major component. It is not surprising that respiratory diseases are a leading cause of death among girls and women over the age of five in India.

The impact on a pregnant, malnourished anaemic woman with chronic lung diseases who cooks in a mountain community would be the greatest, and so would be the effect on her unborn child. Imagine what the effect would be on such a woman who then has to face the added burden caused by deforestation, who has to walk further and further to collect fuel and carry heavy loads of this fuel back home. In the hills, even pregnant women go up steep hill slopes to collect firewood.

Higher Death Rates

Formaldehyde is another pollutant in smoke. It causes irritation in the eyes, nose and throat and usually this irritation begins at 0.1 ppm to 1.0 ppm. Some people can become adapted to 2 ppm to 3 ppm for as long as eight hours without undue comfort. But above 5 ppm most people are extremely uncomfortable and remain so for an hour or more after the end of exposure. Formaldehyde is poisonous to tissues in the lungs and has been found to exacerbate skin wounds. It is considered a human carcinogen and there is evidence that aldehydes and BaP can act synergistically to hasten tumour growth in animals. Studies on the effects of smoking also indicate the kind of impact that wood smoke may have on the health of women. The longer the history of cigarette smoking, the higher the risk. Women begin cooking as young girls and continue for much of their lives. Young girls may receive significant exposure at their mothers' sides even before the often tender age at which they begin cooking full time.

Inhalation of the cigarette smoke increases risk. In the case of cooking smoke, inhalation is inevitable because exposure to smoke comes with every breath and not as a puff once every several breaths. Exposure to cigarette smoke during pregnancy and nursing increases the risks to mother and child. Pregnant and nursing mothers generally have no option but to cook and so remain exposed to smoke.

Chronic obstructive lung diseases like cor pulmonale, cancer, (particularly lung and nasopharyngeal cancer), acute respiratory diseases resulting from the decreased ability of the lungs to clear themselves, and low birth weights of children born to mothers exposed to wood smoke and their increased perinatal mortality and: morbidity are, therefore, among some of the major effects that, can be expected from wood smoke.

There is general agreement that the health of rural women is significantly worse than that of the rural male population. A number of reasons have been presented in the past to explain this phenomenon : high fertility rates, less access to health care, inadequate diets, and differences in economic roles. Smoke exposure could also be one of the major factors.

The famous Khanna study carried out in 11 Punjab villages between 1953 and 1960, with a follow up 10 years later, showed that death rates from all causes were greater for women (except tetanus, which was three times greater among newborn males). The crude death rate was 26 percent higher for women than men. No specific cause could be found to explain this relatively greater death rate. Childbirth accounted for only 28 percent of the difference between male and female death rates, there was a much higher incidence of cancer, tuberculosis and pneumonia amongst women, all of which could be related to higher exposures to wood smoke.

Data from Kaira district in Gujarat also shows that diarrheal and enteric diseases are prominent in both sexes in the one to 15 age group. But beyond that age, respiratory infections take first place with bronchitis, emphysema and asthma attaining a prominent position among women sooner (15-44 years) than in men (45-64 years).

Available Solutions

There are several steps that can be taken to cut down the exposure to smoke while cooking and reduce its adverse impact on health : cleaner fuels, improved stoves and better ventilation. As far as cleaner fuels go, one major option would be to speed up the use of kerosene and electricity. But the government will be unable to supply electricity in the quantities needed for cooking. Moreover, most people are too poor to be able to purchase electricity. Kerosene is cheaper but it too is used in the rural areas more for lighting than for cooking, even though it is subsidised. Kerosene is also a limited fossil resource and can only provide an interim arrangement.

Biogas is another fuel which can greatly reduce the health problems caused by wood smoke. Unfortunately, biogas plants, despite major government programmes, have not spread far and wide, and remain limited mainly to the richer peasant households with an adequate number of cattle. Producer gas is yet another alternative. This gas is made by controlled combustion of biomass like wood or crop residues in low air conditions. But because of the various problems of waste disposal associated with the process, few proposals have been made for residential use of producer gas.

Methanol or ethanol could also be supplied for cooking. These clean, liquid fuels can be made from wood and crops like sugarcane and cassava, but because these commodities are in short supply and expensive, it is very unlikely that they will ever be used in large quantities for cooking.

Choice Of Tree Species

Thus, there are only two options open. Firstly, those species of trees should be planted in social forestry programmes which give off less smoke when burnt. During their study in Gujarat villages, Kirk Smith and his colleagues found that villagers distinguished different species of wood on the basis of relative smokiness. The prices of different types of wood in a nearby urban market were also found to vary between 35 paise and 25 paise per kilo according to their levels of smokiness.

The villagers were using baval *(acacia nilotica)*, neem, mango and other types of wood. According to them, baval was the least smoky, neem the most. Just as yield, disease resistance, fertiliser requirements and other characteristics are carefully considered for choosing a species of tree, low levels of smokiness should also be considered an important quality.

A second major alternative is to increase the use of charcoal. Charcoal is produced by heating wood in the absence of air in underground or other airtight conditions, often for several weeks. As a result, the volatile content is greatly reduced, leaving a low volatility solid. Particulates and other hydrocarbon emissions are released at the charcoal manufacturing stage, and thus, charcoal burns relatively cleanly at the cooking stage, except for potentially high emissions of carbon monoxide. Because formaldehyde emissions from charcoal are low, the eyes do not smart and do not warn the cook about high levels of carbon monoxide build up. Removal of gases through a well fitted chimney will be essential if charcoal is to be used as a major fuel for indoor cooking.

Smokeless Chulhas

The second major solution to the problem is to so design stoves that exposure to smoke is reduced. A simple chimney can be introduced to take the smoke out of the house but this will lead to increased outdoor air pollution. In a meteorological situation, where inversion takes place over many winter months, reducing outdoor pollution is also very important. During these months, exposure to pollutants can increase substantially both for cooks and the village community as a whole.

No better cooking arrangements even for women of better off families

Stoves can also be designed to improve thermal efficiency, that is, to use less fuel to do the same amount of cooking. But recent experiments also show that the steps taken to increase thermal efficiency can sometimes lead to higher rates of emission, and there can thus be a net increase in pollutant emission. In recent years, a number of groups have designed efficient *chulhas* to reduce the rate of deforestation. Though many of these designs include a chimney, some which are supposed to have high thermal efficiency do not incorporate any mechanism to take the smoke out of the house, such as the improved stove of the Tata Energy Research Institute (TERI) in Pondicherry or of the Central Power Research Institute (CPRI) in Bangalore. These stoves have an enclosed combustion chamber but no chimney for inducing natural drafts or removing smoke.

The increase in efficiency attained by enclosing combustion in a chamber is likely also to result in an increase in emission rates, because of improper mixing of air and volatile gases, and lowered burning rates. There is a need to design stoves that have a higher thermal efficiency, reduce the emission of pollutants and incorporate flues (smoke ducts in chimneys).

The first major effort toward improved *chulhas* was made in the 1950s by S.P. Raju who also wrote a famous book called *Smokeless Kitchens For The Millions.* Raju's effort was inspired by an early smokeless stove design, the Hyderabad Engineering Research Laboratory's smokeless HERL *chulhas*, developed in the 1940s. Later, Gandhiniketan Ashram and the All India Village Industries Commission, building on the work of HERL, developed the Magan *chulha*. This *chulha* has three potholes and theoretically reduces fuel use. Magan *chulha* can be made by hand and with entirely indigenous materials, except for the chimney.

Today, in India, a number of institutions are working on improved *chulhas* but few have been able to spread the message. The Department of Non Conventional Sources of Energy has launched a major national programme on dissemination of improved stoves. Under the social forestry programmes aided by international agencies like the World Bank, improved stoves have been distributed by the thousands in many states.

Working first near Chandigarh in a village called Nada and later in other villages of Punjab, former architect Madhu Sarin has taken a different approach. Sarin works closely with the beneficiaries of the new technology, even at the design stage. The new Nada stove, which Sarin helped to pioneer, evolved spontaneously out of the traditional stove in the village when Sarin worked closely with the stove user.

For Sarin, involvement of women in stove dissemination programmes is crucial. She argues that women seldom take decisions even about their own technological needs and the little cash that would be needed to purchase new technologies is denied to them by men. Thus, stove dissemination programmes must be undertaken in a way that they support and increase the confidence of rural women. Sarin is today the most successful improved stove disseminator in India.

Large Schemes Criticised

Sarin is highly critical of large stove distribution programmes because they do not involve the users and often even end up supplying defective stoves which are smoky and consume more wood then before. In Gujarat, Kirk Smith and his colleagues found that even though many families had been given so called smokeless *chulhas* under the social forestry programme, their houses were still full of smoke and walls full of soot. They found that the stoves had not been installed correctly, maintained adequately, or operated properly to reduce smoke levels by great amounts. Poor installation of the chimney often led to leaks in the roofs, according to householders. This, in some cases, prompted the family to cut off the chimney within the room just under the ceiling, thereby allowing the smoke to remain in the house.

In some cases, ash or soot had not been taken out of the chimney or the *chulha*, preventing the exit of smoke. Forgetting to cover the second pothole when it was not needed for cooking allowed smoke to enter the room. Design, too, was faulty in some cases, leading to cracks in the stove. In other cases, smoke backed into the room in the slightest wind.

Some of the faults clearly lay in the design. For example, during the initial stages of lighting the fire, before the draft had been established, most of the smoke would enter the room even in the best of conditions. Unfortunately, this is usually the period of highest emission rates in biomass combustion.

However, the demand for smokeless stoves now seems to be increasing. K.S. Kunjwal, a Gandhian worker from Kausani in Uttar Pradesh has been trying to, promote improved stoves from the

A smokeless chulha

early 1950s. His first was made to help his mother.

"We built a few new smokeless *chulhas* in the villages of Almora then, but because of lack of interest, we soon gave up the work", says Kunjwal. But now he finds that hill people even pay him to make improved stoves to make improved stoves. Sarin also finds a good response from women.

Both say that for women, reduction of smoke levels inside the kitchen is more important than fuel saving. K.S. Jagadish of the Cell for Application of Science and Technology to Rural Areas (ASTRA) in Bangalore also finds that women of Ungra village, where his group is working, are extremely enthusiastic about the smokeless stoves they have been given.

Little girls must work in soot and smoke

Health Or Efficiency ?

In theory, the goals of high efficiency and low emission are not in opposition. Everything else being equal, improved combustion efficiency would serve both needs. Unfortunately, the major technique used to improve stove thermal efficiency is to control the air flow so that the residence time of the flue gases within the stove is increased. This allows for greater efficiency in the extraction of heat from these gases to the pots but this can also lead to lower combustion efficiency and consequently, greater emission factors.

Similarly, the principal method of reducing exposure to smoke is to incorporate flues, but this can often reduce energy efficiency by creating a draft so that the residence time is reduced. Field experience shows that it is only when flues are combined with *chulhas* with holes for two or more pots that similar or greater energy efficiencies are possible. In households where only one pothole is used, the addition of a flue could result in unchanged or lower thermal efficiency. Several improved stoves with one pothole have been developed in India but they still have to be tested for their emission factors.

There are other conflicting problems as well. For instance, less moisture in the fuel is good, for thermal efficiency but reducing the moisture content beyond a point may increase emission. The rate at which solid fuels burn is also critical in controlling emission. At high burning rates, there is better mixing of air and volatile gases and more complete combustion. In industrial furnaces, with a burning rate of more than 100 kilograms per hour, wood burns quite heat cleanly. But in cookstoves, to increase transfer to the pots and improve thermal efficiency, the burning rate has to be minimised.

In small fires with burning rates of a few kilograms per hour, it is more difficult to achieve complete combustion. Emission rates increase manifold in small fires. Very small decreases in the burning rate can produce very large increases in emission. Most cookstoves operate with burning rates of around two kilograms per hour. In such conditions, there is a dramatic increase in the emission of particulates, carbon monoxide and hydrocarbons. Similarly, baffles (a device to break the flow of air) will generally improve efficiency but increase emission.

The increased emission that results from dung and crop residues as compared to wood may be due to the lower temperatures reached. Most of the critical pollutants from biomass combustion are products of incomplete combustion which is greater at lower flame temperatures. Dung burns at lower temperatures, which would lead to higher emission rates. Crop residues include such a wide variety of materials that generalisations about their being better or worse than wood are extremely difficult.

The design challenge in stoves is, therefore, to make stoves which reduce fuel use (increase thermal efficiency) reduce emission of pollutants, incorporate flues, can be built with local skills and materials, and with the participation of the potential beneficiaries.

Because of the shortage of wood, women are being increasingly forced to collect various new types of biomass materials like twigs and weeds, which have never been evaluated for their emission. Several alternative fuels like briquettes of peanut wastes and coir dust are also being considered for commercial sale. These too have never been studied.

House Designs

A third major aspect of the wood smoke solution is to increase ventilation in the homes of the poor. Ventilation improvement could be the least expensive, short term way to reduce smoke exposure. Relatively minor changes in existing structures like adding windows can make substantial changes.

Just closing a two square metre hole in the ceiling of a small kitchen in Gujarat to mimic monsoon conditions resulted in an eightfold increase in smoke exposure for the cook.

Moving the kitchen to a well ventilated area can also make a major difference. Women who cook in a porch, for instance, receive less exposure to smoke. Finally, the entire kitchen can be redesigned to increase ventilation but this means that ventilation considerations be taken into account while building the house.

The Gujarat study found that women in relatively richer households, living in brick houses, were in fact worse off. Mud houses were generally better ventilated. In addition, the mixed and thatch and tile roofs were often quite well ventilated. Some brick homes, on the other hand, had cooking areas that were nearly completely enclosed, with no openings other than doors. Poorer homes were more likely to use poorer and probably smokier fuels.

But stilt there was more exposure to smoke in the brick houses. Unfortunately, house designs are usually decided upon by the males in the house who can neglect the problems of the women. Also, in some cases, fear of theft may prevent households from making large ventilation holes.

It is equally important to study some of the cooking practices. Most women who cook on woodfired *chulhas* generally squat or sit while cooking, This may be an adjustment over years to the high levels of wood smoke. Concentrations of CO and TSP are generally lower near the ground. Thus, it may be much more comfortable being closer to the ground and out of the region of higher smoke density.

Policy Options

These findings on the ill effects of smoke have several implications for those involved in making national energy, environment, housing and health policies. Energy policy makers in India face no other option but to increase the supply of biomass fuels to meet the cooking energy needs of the poor majority. But this means that growing of less smoky tree species and introduction of smokeless stoves should get high priority. Stove designers will also have to ensure that designs are not just maximised to save on fuel but optimised both to save on fuel and reduce emission. Those involved in rural housing will also have to ensure that any designs they make for rural houses have a proper system for guiding the smoke out of the house. Simple ideas that could be incorporated into existing houses to increase ventilation will be very useful, though in many cases it must be recognised that many openings, in mud walls, for instance, will greatly weaken the structure.

There are serious implications for health policy planners in these findings. Clearly, there will be many problems if it is found that lung cancer is far more prevalent in rural areas than generally believed. Just as supply of clean water is now considered an extremely important domestic need in the rural areas, these findings show that supply of clean air is also a matter of high priority for rural women.

Rough calculations show that a ton of particulates from household stoves may actually lead to 500 times more human exposure than a ton of particulates from a coalfired power plant. The cost of an improved smokeless stove may not even be Rs 100. Thus, the cost of eliminating one gram of particulate dose to human beings by installing smokeless stoves may be just about an eighth of eliminating one gram of particulate dose to human beings from a large coal power station. In other words, rural air pollution caused by traditional fuels could be far more serious but more easily controllable than urban air pollution caused by modern fuels.

These findings also pose a serious question to environmentalists : where should they direct their limited financial resources ? Should these resources be used on a priority basis for control of air pollution in the outdoor environment because of, say, thermal power stations, or should the control of indoor air pollution because of woodsmoke get a higher priority?

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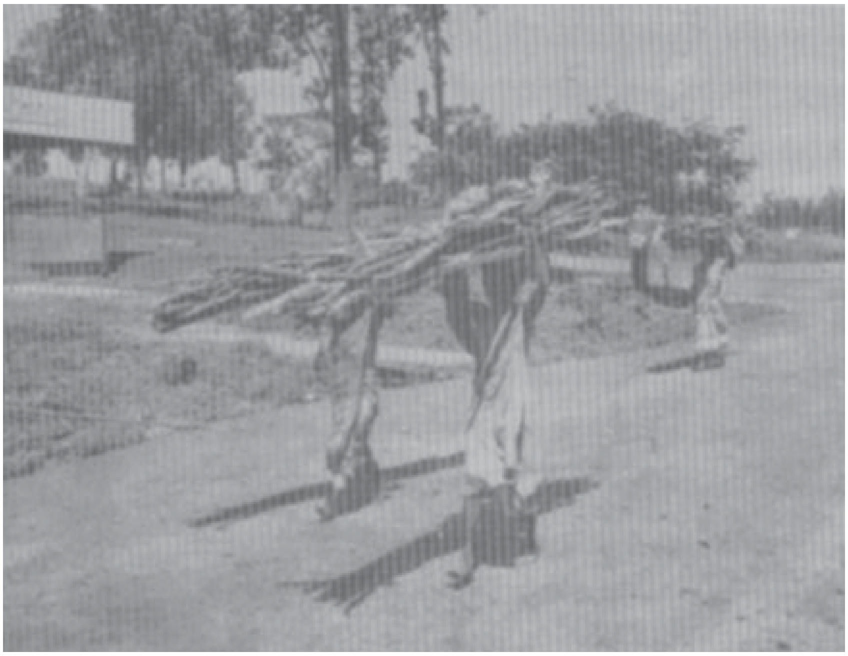

One of the many burdens—fetching firewood