SODIUM HYPOCHLORITE GENERATION FOR HOUSEHOLD WATER DISINFECTION: A CASE STUDY IN NEPAL

by
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ABSTRACT

Low concentration (0.5-0.8%) sodium hypochlorite is a viable solution for point-of-use drinking water chlorination programs in Nepal, and it can be produced on a small-scale at a low cost using relatively cheap, safe, and robust generators, appropriate for developing country conditions.

This thesis describes the set-up and the testing of a sodium hypochlorite generator in Kathmandu, at the laboratory of the Environmental and Public Health Organization, a Nepalese water research institute. The major technical and organizational factors for successful commissioning of a sodium hypochlorite generation program are identified. The 0.56% sodium hypochlorite solution produced by this generator showed an average decay rate of 230 mg/L (0.023%) per month over the first three and half months, if proper production and storage conditions are met. A higher decay rate (0.10% per month) resulted from accidental contamination with iron, by use of an iron spigot, subsequently replaced by a plastic spigot. Protection from iron contamination is essential to ensure sufficient shelf life to the solution. In addition, alkalinization of the solution is recommended to achieve a greater stability.

Chlorine demand of tap water in Kathmandu was found to be about 0.5 mg/L and thus a sodium hypochlorite dose of three drops per liter (about 1.5 mL/L) proved adequate to provide a free residual chlorine level above 0.2 mg/L. However, further investigation of the actual chlorine demand in different seasons and in different areas of the country is suggested. Based on the outcome of such a survey, daily household sodium hypochlorite consumption may be estimated and appropriate re-design of the chlorine dispensing bottle and the dosing cap can be undertaken.

A Business Plan for the marketing of a sodium hypochlorite water disinfectant complements the above technical assessment. The logical framework for establishing a micro-enterprise is presented, and marketing, distribution, and promotion strategies for approaching the three main market segments – urban households, rural households and bulk hypochlorite solution customers – are suggested. Production costs and alternative micro-enterprise structures are evaluated, with specific attention to the issue of the financial viability of the business. Finally, an integrated evaluation of the sustainability of sodium hypochlorite generation in Nepal is presented.

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This thesis would not have been possible without ENPHO's staff, who helped me before, during and after my fieldwork in Kathmandu in January 2002. In particular, I am grateful to Roshan Shrestha and Arinita Maskey for all the logistical support and to Mingma Sherpa whose collaboration was priceless and enjoyable at the same time. Similarly, I am in debt to Jim Brannen from Exceltec International Corporation / Severn Tren De Nora, who answered favorably to request for the donation of the hypochlorite generator. Thanks to his help and the generosity of his company, this project was successfully brought into the implementation phase. My gratitude goes also to Bhikkhu Maitri, who contributed greatly to the project by providing the reaction tank in Kathmandu.

I owe a special thanks to the Fulbright Commission, which supported me financially for this Masters of Engineering program. They had faith in my capacities and gave me the opportunity to study in the United States, giving me access to a new world.

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LIST OF ABBREVIATIONS

AC	Alternating Current (50 or 60 Hz)
AWWA	American Water Works Association
CDC	Centers for Disease Control and Prevention
DBP	Disinfection By-Products
DC	Direct Current
ENPHO	Environmental and Public Health Organization
NRs	Nepali Rupees (exchange rate in January 2002: 1 US$ = 75 NRs)
ME	Micro-Enterprise
M.Eng.	Masters of Engineering in Civil and Environmental Engineering Program at MIT
MIT	Massachusetts Institute of Technology
NGO	Non-Governmental Organization
NOAEL	No Observed Adverse Effect Level
O&M	Operation and Maintenance
POU	Point-Of-Use
FRC	Free Residual Chlorine
TDI	Tolerable Daily Intake
WHO	World Health Organization

1. Introduction

Student teams from the MIT Masters of Engineering in Civil and Environmental Engineering Program (M.Eng.) have researched drinking water quality and household treatment technologies in Nepal since September 1999.

The investigations carried out by the first year team gave a preliminary picture of the water quality situation in Nepal and defined priorities among the many water problems to be addressed. In particular, microbial contamination of drinking water sources and municipal supplies was found to be the main cause of water-borne diseases among the population, especially children, and implementation of point-of-use (POU) treatment, by either chlorine or solar disinfection, was recommended (MIT Nepal Water Project Team, 2000).

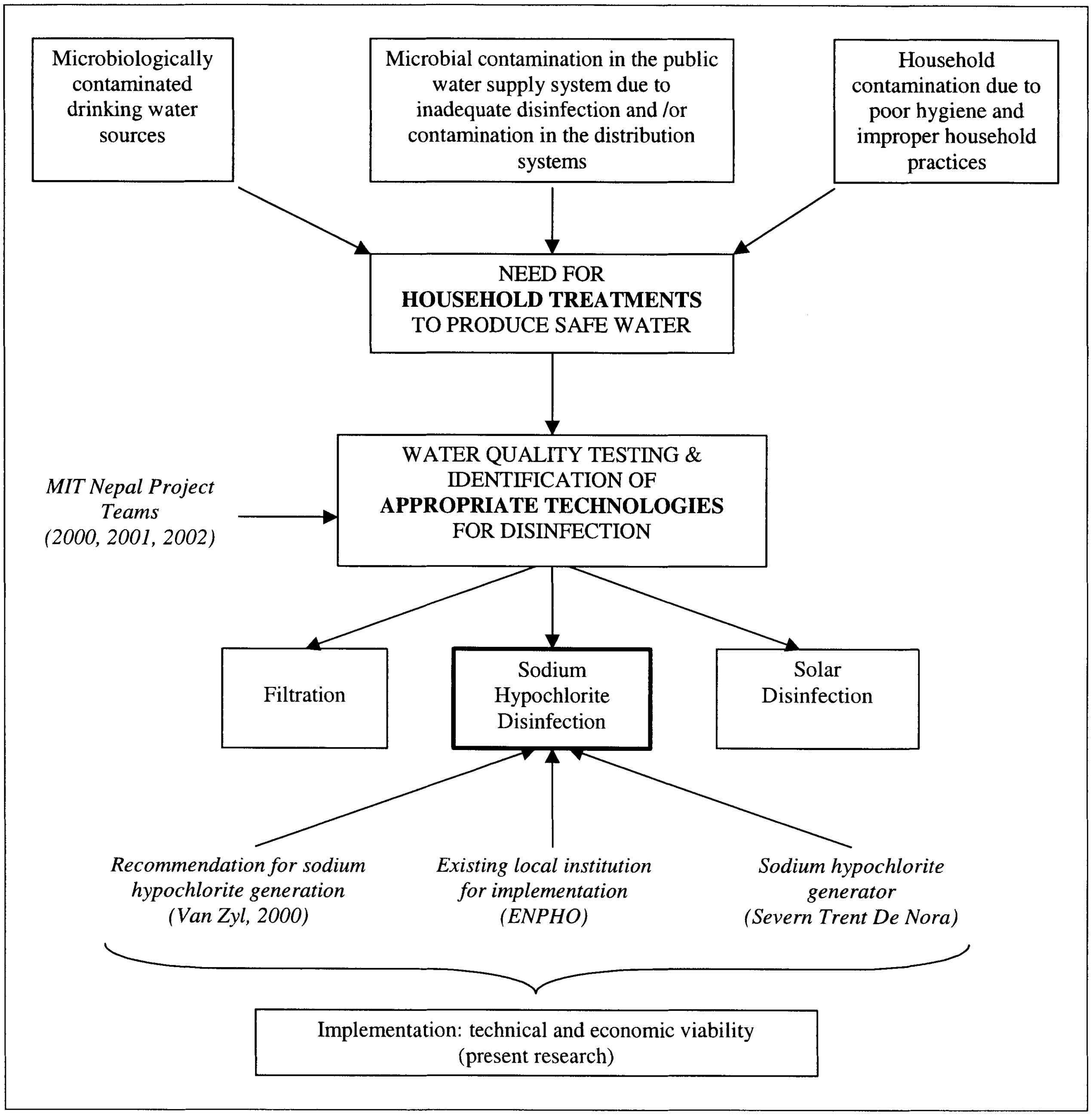
In the area of disinfection options, solar disinfection was specifically studied (Khayyat, 2000; Smith, 2001), while chlorination was considered a less viable alternative mainly because of the shortage of chlorine in Nepal (Khayyat, 2000; MIT Nepal Water Project Team, 2000).

In September 2001, the Nepalese NGO Environment and Public Health Organization (ENPHO), a leading research institute and water-testing lab in the country, invited the current MIT Nepal Water Project Team to further investigate the implementation of chlorination programs in Nepal and to start up local production of sodium hypochlorite. A study carried out by Nadine Van Zyl, another M.Eng. student (2001), was related to this subject: conditions for sodium hypochlorite generation in a developing country were analyzed and a hypochlorite generator with the necessary characteristics to operate under developing country conditions was identified on the US market.

Therefore, technical feasibility of sodium hypochlorite generation in Nepal was preliminarily checked with ENPHO, and, thereafter, the author contacted the manufacturer of the recommended generator and asked for a contribution to the project. In October 2001, the manufacturer, Severn Trent De Nora, donated a SANILEC-6 generator to the MIT Nepal Water Project Team, opening the way for sodium hypochlorite generation in Nepal.

Figure 1.1 provides a graphical representation of the logical framework of which this research is one part.

Figure 1.1 – Logical framework for sodium hypochlorite generation in Nepal



1.1 Objectives

This thesis has two main objectives: (1) reporting on the technical conditions that enabled a successful installation of the sodium hypochlorite generator at ENPHO's laboratory in

Kathmandu, and (2) identifying the key factors for establishing a profitable micro-enterprise that would produce and market sodium hypochlorite in Nepal.

1.2 Scope

Because previous MIT Nepal Water Project teams had determined that sodium hypochlorite was unavailable in Nepal, the research presented in this thesis sought to support ENPHO in starting local sodium hypochlorite generation. Since ENPHO's priorities were (1) having the generator working properly, and (2) developing a sustainable sodium hypochlorite business, the author contributed to those goals by studying the following two related subjects:

1. The procedures for the installation and operation of the SANILEC-6 chlorine generator. A sound knowledge of these procedures was necessary to maximize the generator performance and minimize the time necessary to make it fully operational.

2. The key elements for a sustainable business plan. A robust business plan is indispensable to guarantee the economic and social sustainability of the initiative on the long term.

1.3 Approach

The research included three phases. First, the process of sodium hypochlorite generation was investigated. The author familiarized himself with the generator operational instructions provided by the manufacturer, including maintenance recommendations and trouble-shooting. In addition, literature on similar experiences was reviewed in order to anticipate possible failure factors and identify technical key factors for success.

Second, in January 2002, the author assisted ENPHO in the installation of the sodium hypochlorite generator in Kathmandu, Nepal, and helped in training local personnel. In this period, discussions with ENPHO's staff provided suggestions for the business plan.

Last, the information gained from the field experience was organized in this thesis so that it can be used as an aid to the existing program and as a reference in the implementation of other similar ones.

Verifiable milestones in this project were as follows:

1. Generator donation;
2. Generator shipment to MIT and delivery to Kathmandu, Nepal (via Italy);
3. Generator set-up and testing, including:
    a. Identifying and preparing the proper site to locate the generator;
    b. Implementing proper safety measures;
    c. Procuring the required raw materials;
    d. Testing and treating the raw water;
    e. Running trial production cycles;
    f. Testing of the concentration of the produced chlorine solution;
    g. Adjusting salt and/or water dose;
    h. Determining the actual production rate and production costs;
    i. Verifying sodium hypochlorite stability.
4. Technical and economic recommendations for full-scale production.

2. Chlorine chemistry for disinfection

In this chapter, basic concepts of chlorine chemistry, as related to disinfection, are summarized. Main references are Lawrence (1977), Metcalf & Eddy (1991), Viessman (1993), and AWWA (1999).

2.1 Chlorine compounds

Some chlorine compounds are used to disinfect water because of their capacity to inactivate microorganisms. However, due to high reactivity, these compounds also react quickly with inorganic-reducing substances (ferrous iron, Fe^{++}, manganous manganese, Mn^{++}, nitrites, NO_2^-, hydrogen sulfide, H_2S), ammonia, and organic material commonly present in natural water, generating chlorine Disinfection By-Products (DBP). Chlorine reduces to chloride and it is lost as a disinfectant. In this Section, the main compounds containing chlorine are briefly described.

Chloride ion (Cl^-): is the natural form in which chlorine is present in the environment. It is the most abundant ion in seawater (concentration varies between 18,000 and 25,000 mg/L), where it forms, with sodium, sodium chloride (common salt). It also occurs in fresh water (0-200 mg/L) due to the dissolution of chloride-containing minerals from the soil (mainly sodium and calcium chloride). The chloride ion has no disinfectant action itself, but is the compound used to produce molecular chlorine by electrolysis.

Molecular chlorine (Cl_2): is a poisonous soluble heavy gas (solubility is 7,160 mg/L at 1 atm and 20 °C), with strong oxidizing power. In water, it hydrolyzes readily, producing hypochlorous acid and hydrochloric acid, as shown in Reaction 2.1.

$Cl_2 + H_2O \rightarrow HOCl + H^+ + Cl^-$ *Reaction 2.1 – Molecular chlorine hydrolysis*

Hypochlorous acid (HOCl) and Hypochlorite ion (OCl^-): hypochlorous acid is a weak acid, which partially dissociates in water, forming hypochlorite ion (Reaction 2.2). The concentration of the two species is determined by the dissociation constant ($pK_a = 7.537$ at 25 °C), and depends on the pH and the total concentration of chlorine.

$HOCl \leftrightarrow H^+ + OCl^-$ *Reaction 2.2 - Hypochlorous acid ionization*

Hypochlorous acid is the actual disinfectant agent, while the hypochlorite ion has mainly an oxidizing action. However, due to the equilibrium, as soon as hypochlorous acid is consumed, new acid is produced from the hypochlorite ion, and therefore, hypochlorite ion is considered to have an indirect disinfecting action.

Sodium hypochlorite (NaOCl) and Calcium hypochlorite ($Ca(OCl)_2$): are salts of hypochlorous acid, which hydrolyze in water, producing hypochlorite ion (and consequently hypochlorous acid), as described by Reaction 2.3-4.

$NaOCl + H_2O \rightarrow Na^+ + OH^- + HOCl$ *Reaction 2.3 – Sodium hypochlorite hydrolysis*

$Ca(OCl)_2 + 2\ H_2O \rightarrow Ca^{++} + 2\ OH^- + 2\ HOCl$ *Reaction 2.4 – Calcium hypochlorite hydrolysis*

Sodium hypochlorite is commercially available at different concentrations (1-16% wt available chlorine[1], but usually between 5 and 15%) and is commonly known as bleach. Calcium hypochlorite is generally sold in the dry form (bleaching powder) and contains between 20 and 70 % of available chlorine.

Unstable chlorine-compounds (chloramines): are compounds formed by the reaction of hypochlorous acid with inorganic nitrogen (ammonia, NH_3), as shown in Reaction 2.5-7. The initial concentration depends on the pH of the solution and the total chlorine dosed in the water. Then, their concentration decreases because of hydrolysis. Increasing doses of chlorine provoke chloramines oxidation to nitrogen gas, while chlorine is reduced to chloride ion.

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[1] The meaning of "available chlorine" is explained below in the section.

$NH_3 + HOCl \leftrightarrow NH_2Cl + H_2O$ *Reaction 2.5 – Monochloramine formation*

$NH_3 + 2\ HOCl \leftrightarrow NHCl_2 + 2\ H_2O$ *Reaction 2.6 – Dichloramine formation*

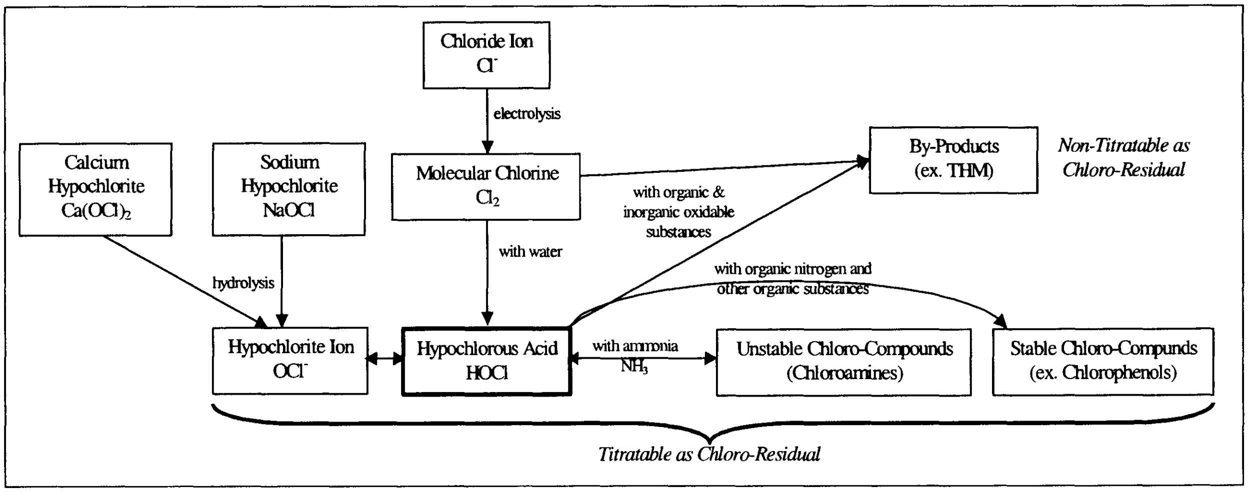
$NH_3 + 3\ HOCl \leftrightarrow NCl_3 + 3\ H_2O$ *Reaction 2.7 – Trichloramine formation*

Stable chlorine-compounds: are mainly chloro-phenols and organic nitrogen compounds, that do not have any disinfectant action, but that are titrated together with the other disinfecting species above. If their concentration is within the range 0.1-0.5 mg/L, these compounds should be taken into account when determining free residual chlorine concentration (see below).

Chlorination by-products: both molecular chlorine and hypochlorous acid react with organic oxidable compounds naturally occurring in fresh water such as humic and fulvic acids, producing chlorine Disinfection By-Products (DBP).

These by-products do not disinfect and are not detectable by titration. Some DBP groups, such as trihalomethanes (THM) and haloacetic acids (HAA), are suspected to affect human health, causing cancer. Extensive literature on this subject is available from USEPA (1997) and other sources.

Figure 2.1 – Chlorine compounds involved in disinfection processes



Because of the multiple equilibria existing between hypochlorous acid, hypochlorites, and chloramines, some aggregate measures of chlorine content are commonly used in the analytical practice and for commercial purposes.

Available chlorine is a measure of the oxidizing capacity of a solution in terms of equivalent molecular chlorine. One mole of molecular chlorine can accept two moles of electrons, as shown in Reaction 2.8, and this is assumed as the reference point (100% of available chlorine).

$Cl_2 + 2\ e^- \rightarrow 2Cl^-$ *Reaction 2.8 – Molecular chlorine reduction*

A mole of hypochlorite can also accept two moles of electrons, as shown in Reaction 2.9; therefore, the oxidizing capacity of hypochlorite is considered the same as molecular chlorine.

$OCl^- + 2\ e^- + 2\ H^+ \rightarrow Cl^- + H_2O$ *Reaction 2.9 – Hypochlorite ion reduction*

One mole of sodium hypochlorite, which contains 1 mole of hypochlorite ion, is also equivalent to 1 mole of molecular chlorine (MW 70.91 g/mol). Since molecular weight of sodium hypochlorite is 74.5 g/mol, it can also be said to contain 70.91 / 74.5 = 95.8 % (wt) available chlorine. Similarly, 1 mole of calcium hypochlorite is said to contain 99.2 % (wt) available chlorine, since 1 mole of it (143 g/mol) produces 2 moles of hypochlorite (Reaction 2.4), each of which is equivalent to a mole of molecular chlorine (total of 2 x 70.91 = 141.82 g/mol, divided by 143 g/mol = 99.2% wt).

Note that these percentages of equivalent chlorine are different from the percentages expressing the dilution of aqueous solutions of sodium or calcium hypochlorite. For example, if a sodium hypochlorite solution at 5.25% (wt) available chlorine is provided, it means that the solution contains 52.5 g equivalent chlorine per 1000 g solution. According to the percentage above, this means that 52.5 / 95.8 % = 54.8 g sodium hypochlorite are actually present in 1000 g solution.

Applied Chlorine is the concentration of available chlorine in the treated water after a given dosage of a pure chlorine disinfectant, calculated according to the dilution.

Chlorine Demand is defined as the quantity of available chlorine consumed by water impurities.

Free (Residual) Chlorine is an aggregate measure of the quantity of chlorine compounds that, after the dosage, has not reacted with ammonia or organic matter, i.e. molecular chlorine, hypochlorous acid, and hypochlorite ion, each of them expressed as available chlorine.

Combined (Residual) Chlorine, complementarily, measures the amount of chlorine that has reacted with ammonia forming chloramines. Combined chlorine is important since chloramines are not detectable as free chlorine, but still provide disinfecting action.

Total (Residual) Chlorine is the total amount of chlorine compounds detectable by titration. If no organic matter, phenols or organic nitrogen are present in the water, no stable chlorine compounds are formed and total residual chlorine equals the sum of the free and combined chlorine.

Figure 2.2 – Compounds that originate from chlorination

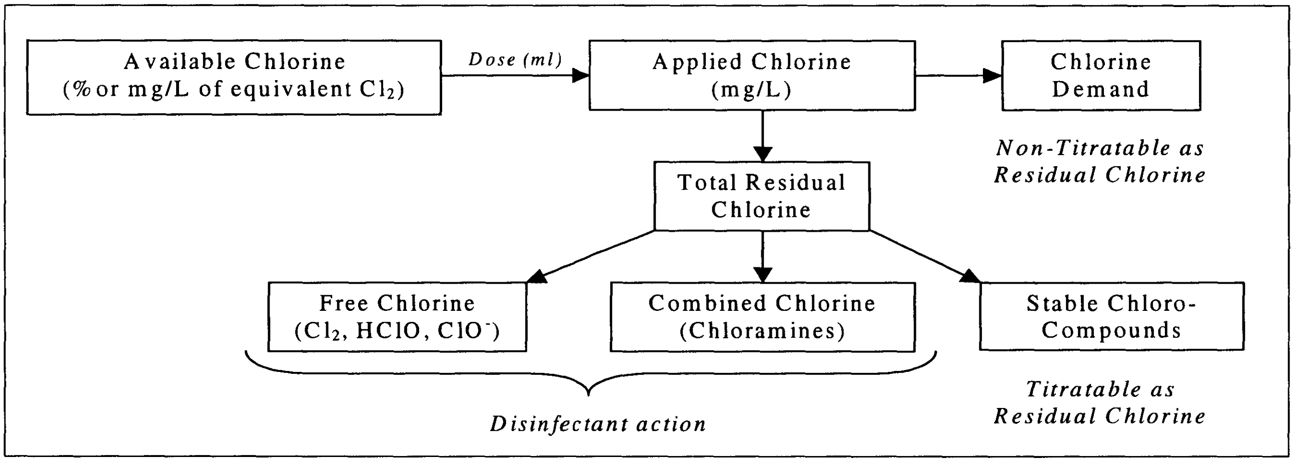
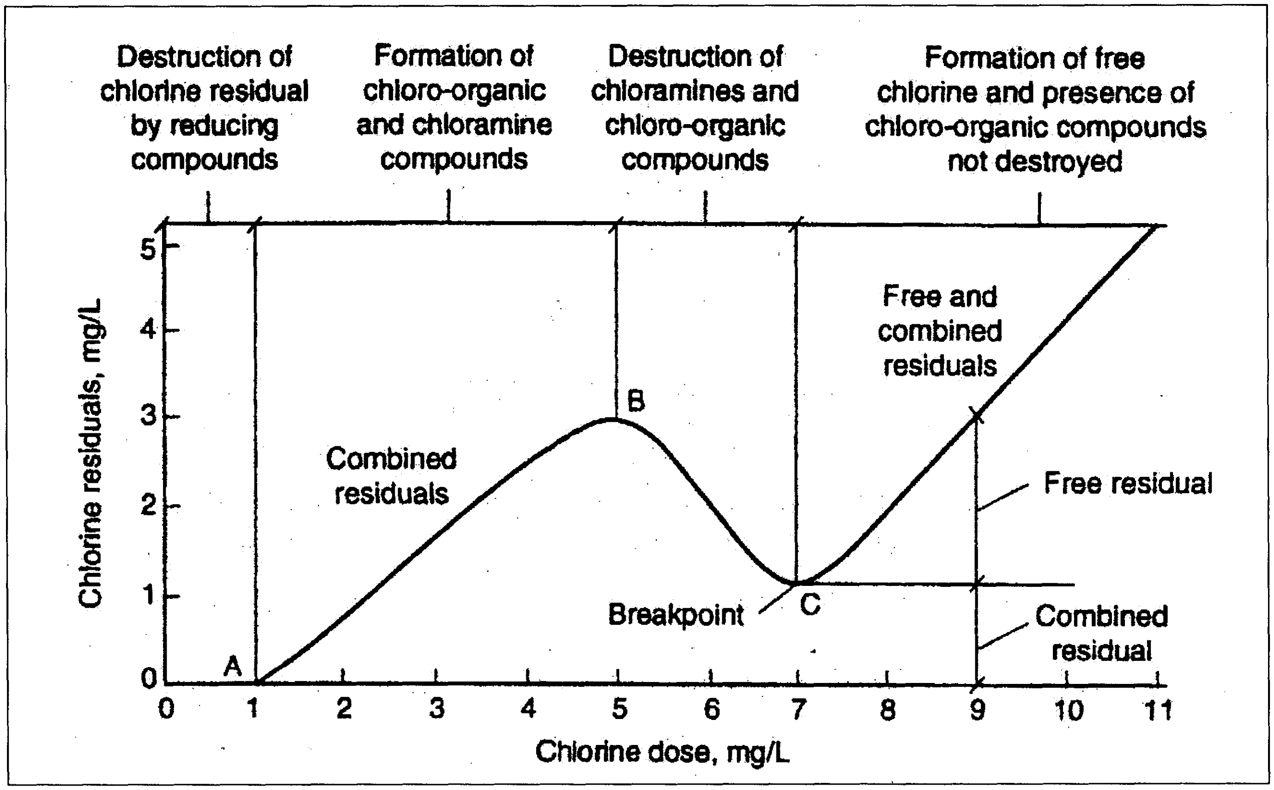


Figure 2.3 (Metcalf &Eddy, 1991) shows an explicatory curve of the evolution of chlorine forms with increasing available chlorine dosage. First, compounds such as Fe^{2+}, Mn^{2+} and H_2S, and organic matter are oxidized. Chlorine is reduced to chloride and no residual chlorine is developed (from point O to point A). Then, chlorine reacts with ammonia and produces chloramines, according to Reaction 2.5-7 (segment from point A to point B). If chlorine dose is sufficiently high, chloramines are slowly destroyed after formation, until only stable chloro-compounds are left (point C, defined as the "breakpoint" of the curve). In the oxidation of the chloramines, nitrogen gas (N_2) and nitrous oxide (N_2O) are produced while chlorine is reduced to

chloride ion. Therefore, between point B and C the disinfecting action of chlorine is decreasing, since chloramines concentration is decreasing. After the breakpoint, additional available chlorine will results in proportional increase of free residual chlorine, and disinfecting action increases again (and more sensibly, since hypochlorous acid has a stronger bactericidal action than chloramines).

Figure 2.3 – Chlorination breakpoint curve



2.2 Chlorine detection

Several methods are available for measuring both available chlorine and residual chlorine (total or free) in water solutions. The *Standard Method for the Examination of Water and Wastewater* (1998) (STEWW) describes eight of them, based on five different principles (iodometric titration, amperometric titration, DPD method, syringaldazine method, iodometric electrode).

In addition, chemical companies have developed their analytic methods and, in particular, those proposed by HACH Company have been applied in the experiments conducted in Nepal in January 2002. More details about the methods adopted in Nepal are given in Section 4.5.1.

2.3 Commercial chlorine products

Chlorine for disinfection is produced and commercialized both as chlorine gas, sodium hypochlorite (liquid bleach) or calcium hypochlorite (bleaching powder). To reduce transportation cost, high chlorine content to volume ratio is generally adopted for every form.

Chlorine gas is industrially manufactured as a by-product in the Kellner-Solvay process used to make caustic soda, through the electrolysis of brine (Reaction 2.10). Then, chlorine is condensed through compression above its vapor pressure, with a reduction in specific volume of 450-fold. Finally, it is shipped and sold in tanks of size varying between 45.5 kg and 1000 kg.

$2\ NaCl + 2\ H_2O \rightarrow Cl_2 + H_2 + 2\ NaOH$ *Reaction 2.10 – Industrial preparation of molecular chlorine*

Commercial sodium hypochlorite is produced in 5 to 16 % (wt) available chlorine solutions, through reaction of chlorine gas with caustic soda (Reaction 2.11). Solutions between 1 and 5% are common for domestic use, while solutions between 5 and 16% are for industrial customers. On-site production is also possible, as described in more detail in Section 2.5.

$2\ NaOH + Cl_2 \rightarrow NaOCl + NaCl + H_2O$ *Reaction 2.11 – Industrial preparation of sodium hypochlorite*

Calcium hypochlorite is industrially manufactured according to Reaction 2.12:

$2\ Ca(OH)_2 + 2\ Cl_2 \rightarrow Ca(OCl)_2 + CaCl_2 + 2\ H_2O$ *Reaction 2.12 – Industrial preparation of calcium hypochlorite*

The final product is a white dry solid, in the form of powder, granules, compressed tables or pellets, with available chlorine content up to 70 % (wt), but usually, for water disinfection purposes, between 25 and 28%. If 100 g of powder at 25% available chlorine are added in 1 liter of pure water, a solution with 25 g available chlorine per liter is formed (2.5 % solution).

Among these chemicals, chlorine gas is the cheapest, in terms of cost per unit of available chlorine. Therefore, it has been the prevailing system adopted for water disinfection in USA and Western Europe. However, the risks related to highly toxic chlorine transportation and handling have determined, in some cases, a bias for sodium hypochlorite, despite the fact its price ranges from 150 to 200 % of the cost of compressed chlorine gas.

Calcium hypochlorite is the most expensive form among the three main chlorine disinfectants. It tends to crystallize, clogging metering pumps, piping and valves, and looses available strength if not properly stored in a cool and dry location. Therefore, its use is limited to small installations, where chlorine gas and sodium hypochlorite systems are inapplicable because of their complexity.

Because of these characteristics, sodium hypochlorite might be considered the most adequate forms of chlorine for implementing point-of-use disinfection. Khayyat (2000) provides a discussion of this topic.

2.4 Safety risks related to chlorine gas

Concern about chlorine gas use rises from the risk of fumes inadvertently released into the atmosphere. Chlorine gas's effects on skin, body tissues, and respiratory system go from irritant to burning to fatal. Inhalation of chlorine vapor at concentration as low as 5 ppm by volume already provokes difficulties in breathing; at 30 ppm (vol) irritation of the respiratory system gives origin to coughing and concentration of 1000 ppm (vol) provokes death in few minutes.

Specific safety devices are provided to personnel handling chlorine gas tanks and cylinders. However, the risk of spills that can be released because of accidents in transportation, storing and handling on a water treatment plants has often been an incentive for communities to use liquid hypochlorite disinfection instead. The city of Ocoee, Florida, is just one example in United

States of a community that has chosen on-site sodium hypochlorite generation against chlorine gas, mainly for safety reasons (Exceltec, 2001).

2.5 *On-site sodium hypochlorite generation*

On-site generated sodium hypochlorite has been used for water disinfection in the USA since the early 1970s (Ainsworth, 1997). The main rationale for its adoption in place of chlorine gas or industrial sodium hypochlorite, despite the higher cost, is the lower level of risk and safety measures required, because of the available chlorine concentration (0.5-0.8%) below the threshold for hazardous classification (1%). In addition, the low concentration provides more stability (see next section). Also, a low concentration solution causes less scaling of injection lines and fittings, because of the lower pH (about 9, instead of 12-13 of commercial bleach). The major disadvantages of the on-site generation are the cost for the energy and the replacement of the electrodes. These are usually made of expensive materials, such as titanium coated with iridium, ruthenium, titanium or platinum oxides, assembled in proprietary units with an average lifetime of 5-8 years (White, 1999). In contrast, because of the simplicity of the system, maintenance and operation cost are modest. Table 2.1 (adapted from Exceltec[2], 2002 c) summarizes the main differences between the two solutions.

Table 2.1 – Comparison of on-site generated and industrial sodium hypochlorite

Concern	***12-15% Purchased NaOCl***	***0.5-0.8% On-site generated NaOCl***
Corrosion and leakage	PVC piping suggested Risk of leakage at fittings	Not an issue
Scaling	Extreme scaling when in contact with hard water	Not an issue
Product degradation	Shorter shelf life	Less than 0.1% decay per month
Chlorine gas production	Risk if pH is reduced	Not an issue
Storage	FRP or HDPE	FRP or HDPE
Safety and regulatory	Hazardous product	Not hazardous product

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[2] Exceltec International Corporation is the company that manufactures the sodium hypochlorite SANILEC-6. It is now a part of Severn Trent De Nora, a joint venture between Severn Trent Plc and De Nora. Severn Trent's US operation are combined under the umbrella of Severn Trent Services.
(About Exceltec, http://www.exceltecorp.com/about/index.html, accessed on 5/7/2002).

The generation process is simple: a brine solution of water and sodium chloride (NaCl) undergoes electrolysis, and chlorine gas is generated inside the solution at the anode while hydrogen is generated at the cathode.

$2\ Cl^- \rightarrow Cl_2 + 2\ e^-$ *Reaction 2.13 – Sodium hypochlorite generation: cathode reaction*

$2\ H_2O + 2\ e^- \rightarrow H_2 + 2\ OH^-$ *Reaction 2.14 – Sodium hypochlorite generation: anode reaction*

Still in the electrolytic cell, chlorine gas reacts with water to form hypochlorous acid, according to Reaction 2.1. Including the non-reactive sodium ion, the overall Reaction 2.15 is obtained:

$NaCl + H_2O \rightarrow NaOCl + H_2$ *Reaction 2.15 – Overall sodium hypochlorite generation reaction*

Theoretically, inefficiencies can occur from the cathodic reduction of hypochlorite to chloride and the anodic oxidation of hypochlorite to chlorate (Reaction 2.16-17). However, these reactions are minimized by the low hypochlorite concentrations maintained during the process, and by optimizing the flow rate to the actual salt concentration range, pH range, and water temperature range under which sodium hypochlorite generators usually operate.

$OCl^- + H_2O + 2\ e^- \rightarrow Cl^- + 2\ OH^-$ *Reaction 2.16 – Chloride formation*

$6\ OCl^- + 3\ H_2O \rightarrow 2\ ClO_3^- + 4\ Cl^- + 6\ H^+ + 3/2\ O_2 + 6\ e^-$ *Reaction 2.17 – Chlorate formation*

While Reaction 2.16 is of concern only from an efficiency point of view, Reaction 2.17 draws attention to the risk of formation of chlorate (ClO_3^-), whose effect on health is under study. Chlorate was used as an herbicide and methemoglobinemia, hemolysis and renal failure have been observed because of chlorate poisoning. However, specific toxicology tests on monkeys and humans showed no clinically significant effects, even at concentrations much higher than common in disinfected water (USEPA, 1994).

Besides, content of chlorate is lower in on-site generated hypochlorite than in commercial bleach (Ainsworth, 1997), since the formation rate is higher for increasing concentration of hypochlorite (Gordon, 1997).

2.6 Sodium hypochlorite stability

Stability is a major concern in the use of sodium hypochlorite as a disinfectant. Both hypochlorous acid and hypochlorite ion in water solution undergo a decay process, whose rate depends on exposure to light (UV), temperature, pH, initial available chlorine concentration and presence of organic matter and metal ions (Hoffman, 1981; Gordon, 1997).

Table 2.2 shows data available from sodium hypochlorite decay studies. Research has generally focused on industrial solutions, with available chlorine concentrations around of 15%, while data for dilute solutions (0.5%), such as those produced by on-site generation, are less readily available, probably because in such applications sodium hypochlorite is intended for immediate use and, therefore, the decay rate of the solution is not an issue.

Table 2.2 – Sodium hypochlorite decay data

Initial % of available chlorine	***Storage conditions*** (in all cases protection from light was provided)	***Decay data (% of available chlorine at given time or half-life)***	***Reference***
18.0	Ambient temperature	Half-life: 60 days (2 months)	AWWA (1999)
16.7	26.7 °C / 80 °F	15.0 after 10 days (-10%) 13.4 after 25 days (-20%) 11.7 after 43 days (-30%)	Metcalf & Eddy (1991)
16.0	25 °C / 77 °F	Half time: 61.7 days	Gordon (1997)
5.0	4 °C / 39 °F	Stable after 200 days	Piskin (1995)
5.0	24 °C / 75 °F	4.95 after 22 days (-1%) 4.50 after 43 days (-10%) 4.00 after 85 days (-25%) 3.35 after 200 days (-32%)	Piskin (1995)
3.0	Ambient temperature	Half-life: 1700 days (4.6 years)	AWWA (1999)
0.5	4 and 24 °C / 39 and 75 °F	Stable after 200 days	Piskin (1995)

Although there is some variability, the data generally indicates that decay rates are higher at higher concentration and higher temperature. More detail on the effect of the concentration and temperature is provided in Table 2.3 (White, 1999).

Table 2.3 – Sodium hypochlorite half-life values at different concentrations and temperatures

Half-life constant (Days)	***Temperature***			
Initial % of available chlorine	***100 °C 212 °F***	***60 °C 140 °F***	***25 °C 77 °F***	***15 °C 59 °F***
10.0	0.079	3.5	220	800
5.0	0.25	13.0	790	5000
2.5	0.63	28.0	1800	N/A
0.5	2.5	100	6000	N/A

There are three main pathways of hypochlorite decomposition (Hoffman, 1981):

a) Spontaneous decay because of interaction between hypochlorous acid and hypochlorite ion. Reaction 2.18 shows that highly oxidizing hypochlorous acid molecules may transfer oxygen atoms to hypochlorite ions, being reduced to hydrochloric acid, with contemporary formation of chlorate (ClO_3^-).

$OCl^- + 2\ HOCl \rightarrow ClO_3^- + 2\ HCl$ *Reaction 2.18 – 1st decay pathway of hypochlorite solutions*

The formation of hydrochloric acid reduces the pH of the solution, favoring the formation of new hypochlorous acid. The decay process is then accelerated because of the presence of more hypochlorous acid. To inhibit this mechanism, in many commercial hypochlorite solutions, pH is kept above 12 with excess of sodium hydroxide (NaOH), so that chlorine is mainly in the form of more stable hypochlorite ions, and the decay is minimized.

b) Photolysis. Light, especially UV, can break the hypochlorite ion as shown in Reaction 2.19, with formation of chorite ions.

$2\ OCl^- + UV \rightarrow ClO_2^- + Cl^-$ *Reaction 2.19 – 2nd decay pathway of hypochlorite solutions*

Industrial commercial solutions are usually packed in opaque plastic bottles, with thick wall and/or dark color, which minimize light penetration.

c) Catalytic decomposition. Transition metals such as iron, manganese, nickel, copper, and cobalt can catalyze the decomposition of hypochlorite into oxygen and chloride. Iron is considered the worst offender of sodium hypochlorite stability, causing rapid deterioration of a 15% solution in a few days already at concentrations as low as 0.5 mg of iron per liter (White, 1999). Copper produces similar effects at concentrations around 1.0 mg/L (White, 1999).

In Section 4.5.6, data are provided for the decay of the sodium hypochlorite solution produced in Nepal in January 2002.

2.7 Chlorine use, application and efficacy

Chlorination aims to inactivate waterborne pathogens. For the disinfection treatment to be effective, adequate dose of chlorine and contact time must be provided. Table 2.4-4 (CDC, 2002a) list the reduction in bacteria, virus and protozoa contamination for given combinations of residual free chlorine and contact time under specific conditions of pH and temperature of the water.

Table 2.4 – Effect of chlorination on inactivating selected bacteria

Bacteria	***Cl_2 Residual (mg/L)***	***Temp. (°C)***	***pH***	***Contact Time (min.)***	***Reduction (%)***	***Reference***
Campylobacter jejuni	0.1	25	8.0	5	99.99	Blaser et al, 1986
Escherichia coli	0.2	25	7.0	15	99.99	Ram and Malley, 1984
Legionella pneumophila	0.25	21	7.6-8.0	60-90	99	Kuchta et al, 1985
Mycobacterium chelonei	0.7	25	7.0	60	99.95	Carson et al, 1978
Mycobacterium fortuitum	1.0	?	7.0	30	99.4	Pelletier and DuMoulin, 1987
Mycobacterium intracellulare	0.15	?	7.0	60	70	Pelletier and DuMoulin, 1987

Pasteurella tularensis	0.5-1.0	10	7.0	5	99.6-100	Baumann and Ludwig, 1962
Salmonella Typhi	0.5	20	?	6	99	Korol et al, 1995
Shigella dysenteriae	0.05	20-29	7.0	10	99.6-100	Baumann and Ludwig, 1962
Staphylococcus aureus	0.8	25	7.2	0.5	100	Bolton et al, 1988
Vibrio cholerae (smooth strain)	1.0	20	7.0	< 1	100	Rice et al, 1993
Vibrio cholerae (rugose strain)	2.0	20	7.0	30	> 5 orders of magnitude	Rice et al, 1993
Yersinia enterocolitica	1.0	20	7.0	30	92	Paz et al, 1993

Table 2.5 – Effect of chlorination on inactivating selected viruses

Virus	***Cl_2 Residual (mg/L)***	***Temp. (°C)***	***pH***	***Contact Time (min.)***	***Reduction (%)***	***Reference***
Adenovirus	0.2	25	8.8-9.0	40-50 sec.	99.8	Clarke et al, 1956
Coxsackie	0.16-0.18	27-29	6.9-7.1	**3.8**	99.6	Clarke and Kabler, 1954
Hepatitis A	0.42	25	6	1	99.99	Grabow et al, 1983
Norwalk	0.5-1.0	25	7.4	30	Not completely inactivated	Keswick et al, 1985
Parvovirus	0.2	20	7.0	3.2	99	Churn et al, 1984
Poliovirus	0.5-1.0	25	7.4	30	100	Keswick et al, 1985
Rotavirus	0.5-1.0	25	7.4	30	100	Keswick et al, 1985

Table 2.6 – Effect of chlorination on inactivating selected protozoa

Protozoa	***Cl_2 Residual (mg/L)***	***Temp. (°C)***	***pH***	***Contact Time (min.)***	***Reduction (%)***	***Reference***
Cryptosporidium parvum	80	25	7.0	90	90	Korich et al, 1990
	Cryptosporidium oocysts are extremely resistant to chlorine. The use of chlorine alone should not be expected to inactivate *C. parvum* oocysts in drinking water.					
Entamoeba histolytica	1.0	22-25	7.0	50	100	Snow, 1956
Giardia lamblia	1.5	25	6.0-8.0	10	100	Jarroll et al, 1981
Naegleria fowleri	0.5-1.0	25	7.3-7.4	60	99.99	de Jonckheere and van de Voorde, 1976

As shown by the reduction percentage column, chlorination is highly effective against most bacteria and viruses, if residual concentrations about 1 mg/L and contact time in the order of 30 min. are provided. Chlorine efficacy is limited with protozoa such as *Cryptosporidium parvum*, which, in fact, have been recently addressed as an emerging health threat (Fox, 1996). Other commonly applied water treatments, such as filtration, are required to remove effectively *Cryptosporidium* cysts.

No specific adverse effect is reported for humans and animals ingesting water with residual chlorine at the concentrations typically employed in water disinfection (WHO, 1993a). The WHO sets a guideline for maximum residual free chlorine of 5 mg/L, based on a Tolerable Daily Intake (TDI) of 150 μg/kg of body weight. This is derived from a "No Observed Adverse Effect Level" (NOAEL) for the absence of toxicity in rodents ingesting 15 mg of chlorine per kg of body weight per day in drinking-water for 2 years and incorporating an uncertainty factor of 100 for intra- and inter- species variation, with an allocation of 100% of the TDI to drinking-water (WHO, 1993a). However, residual chlorine produces unpleasant taste and odor, which can be perceived by some individuals at levels as low as 0.3 mg/L (WHO, 1993b). A level of residual free chlorine between 0.6 and 1.0 mg/L is commonly considered acceptable in drinking water. Balancing health safety and taste acceptability, most of national legislations prescribe free chlorine residual after disinfection between 0.2 and 0.5 mg/L, in order to guarantee sufficient protection in the water distribution system and acceptable taste at the point-of-use.

Due to the high reactivity of chlorine with the many organic and inorganic compounds usually present in natural water, the chlorine dose that produces the targeted residual chlorine must be determined in each specific case, based on the analysis of water chlorine demand immediately before disinfection. The work of Haas and colleagues extensively reviews the existing practice of chlorine disinfection in United States (Haas, 1992) and the models available for assessing chlorine dose and kinetics (Haas, 1995). Instead of calculating the required chlorine dose based on a specific water analysis, automatic on-line residual chlorine devices are commonly installed at the outflow of water treatment plants, making it possible to regulate chlorine dose according to the fluctuations in water quality and the resulting residual free chlorine detected.

Where point-of-use treatment is practiced, the chlorine demand has to be empirically determined. Such assessment can be done with a simple iterative procedure, as suggested by CDC (2002c) and described in Appendix F. Alternatively, a conservative chlorine dose can be suggested, which covers peaks of chlorine demand during different seasons and weather conditions, even if high chlorine residuals are likely to occur in low chlorine demand periods, resulting in an unpleasant taste.

3. Chlorine disinfection in Nepal

3.1 Background

Water supply service in Nepal is still under major development. According to the World Bank (2001a), 67% of the country's population has access to safe water. However, surveys conducted by ENPHO (Shrestha, 2001) and direct observations and testing during three field seasons of the MIT Nepal Water Project suggest that the above statistics are optimistic and the actual quality of water supply service is still far from satisfaction.

Piped water is available in the Kathmandu valley and a few other urban municipalities, serving about 87.5% of the urban population, which is 12% of the total, but most customers receive water less than 4 hours per day (World Bank, 2001a). Zero or negative pressure in the pipes causes infiltration of contaminated water into the distribution pipes from soil or leaking wastewater channels, which often run close to water lines. This mechanism, combined with lack of or insufficient disinfection at the water treatment plants, results in piped water being bacteriologically unreliable, as assessed in several studies (World Bank, 2001a; Shrestha, 2001).

In the rural areas, where 88% of the population lives, water supply coverage of any kind was said to be 61% in 1996, but microbial and chemical quality requirements for drinking use are still far from being met (World Bank, 2001b). Almost no water treatment at the source is practiced. People without any public water supply get water from natural sources, such as rivers, springs and ponds, which often are microbiologically contaminated.

Because of the general situation of unsafe drinking water, both rural and urban population demand disinfection treatments that can be implemented at the household level (Murcott, 2001). Research conducted since autumn 1999 by the Masters of Engineering students of the MIT Nepal Water Project have identified several appropriate technologies to address this demand and, among other solutions, have suggested sodium hypochlorite as a viable point-of-use disinfectant (Khayatt, 2000).[3]

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[3] Consistently with M.Eng. students findings, the Centers for Diseases Control and Prevention (CDC), an agency of the U.S. Department of Health and Human Services, suggests hypochlorite disinfection as a viable technology for household disinfection and has prepared the Safe Water System (SWS) Handbook, for planning and implementing

No chlorine disinfection at household level is actually practiced, since chlorine disinfectants are not readily available. Other household disinfection methods such as boiling and filtering through a candle filter are widely known in urban areas but not always used. Table 3.1 summarizes the situation of chlorine disinfection practice in Nepal.

Table 3.1 – Chlorine disinfection practice in Nepal

	Area	
	Urban	*Rural*
At central level (water treatment plant)	Chlorination with calcium hypochlorite is typically performed discontinuously due to supply issues or inadequate O&M. Contamination in the distribution system suggests inadequate chlorine residual levels in the treated water as well as problems of infiltration	Does not exist
At household level	Does not exist	

3.2 Chlorine availability

Before January 2002, three types of disinfecting products containing chlorine were available in Nepal: imported bleaching powder (calcium hypochlorite), a locally manufactured calcium hypochlorite solution, called Piyush, and imported house-cleaning detergents, such as Brisk™ and Harpic™.

The first two products are suitable for drinking water disinfection, while products in the last group cannot be used for this purpose since they contain deodorants and fragrances and are intended for house-cleaning only.

Bleaching powder is imported from India by a wholesaler who mainly supplies the six water treatment plants in the Kathmandu area. However, sometimes the municipal water supply is not chlorinated. In addition, the importation is not consistent and treatment plants often experience chlorine shortage (Khayyat, 2000). In January 2000, the bleaching powder stored at the

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household disinfection programs in developing countries. Sullivan (2002) has reviewed past experiences with the SWS approach, including recommendations based on a specific application, with modifications, in rural Nepal.

Sundarighat water treatment plant was analyzed, and the available chlorine content was found to be between 2.5 and 4.5 % (wt), less than the expected value of 5% printed on the label (Khayyat, 2000). Likely, the storage in an area exposed to the elements had provoked the decay in the chlorine content.

Piyush is a 0.5 % calcium hypochlorite solution manufactured by ENPHO since 1998. ENPHO aimed to provide a specific product for household water disinfection to substitute for boiling, which uses imported fossil fuels or wood in a country already suffering from severe deforestation. In January 2002, a new process for on-site production of sodium hypochlorite was introduced (see Chapter 4), in order to replace imported calcium hypochlorite in Piyush manufacturing. The two formulations of Piyush are referred to in this thesis as "former Piyush" (calcium hypochlorite) and "new Piyush" (sodium hypochlorite).

3.3 Production process of the former Piyush

Before January 2002, Piyush was produced using bleaching powder purchased from a wholesaler importing it from India. The bleaching powder had available chlorine content about 25% (wt); thus, 20 g of powder dissolved in 1 liter of water resulted in a solution with 5 g available chlorine per liter, i.e. 0.5%. If occasionally the bleaching powder had available chlorine content differing from the expected, the solution concentration was corrected adding more bleaching powder or more water. Distilled water obtained from the ion exchanger in ENPHO lab was used to dissolve the bleaching powder. Mixing of the solution was provided manually, while pouring the bleaching powder in the reaction tank. An ENPHO technician was in charge of preparing the solution and supervising the bottling phase, carried out by unskilled part-time workers.

There were two main problems with this process:

- Bleaching powder was not always available from the wholesaler or from the water treatment plants; therefore Piyush production was subject to uncontrollable discontinuity.
- During preparation of the stock solution, consistent lime precipitate was formed. Therefore, overnight settling was required before bottling the supernatant. In addition, the precipitated lime posed a disposal problem.

The sodium hypochlorite on-site generation process introduced in January 2002 aimed to solve both these problems.

3.4 Production cost of the former Piyush

ENPHO spent approximately 10 NRs per 60-ml bottle of Piyush produced. Table 3.2 presents a cost break-down, based on unit prices provided by ENPHO and production conditions similar to what has been adopted in the new production process since January 2002 pilot runs, so that Table 3.2 is comparable to Table 5.7 (production cost of the new Piyush).

Two major cost categories have been considered: manufacturing cost and bottling cost. The former includes expenses related to the preparation of the calcium hypochlorite solution; the latter refers to those expenses encountered after the manufacturing process, when the bulk solution is placed in the 60-ml bottles that are sent to distribution and sale. Capital amortization for initial equipment purchase, reserve for replacement and maintenance costs should be considered in a third distinct category. However, the very low-tech process makes these expenses negligible, since there is no other equipment than one plastic reaction tank, which does not require any maintenance. In contrast, these costs are included in the analysis of the new production process, since the sodium hypochlorite generator is involved (see Section Production cost analysis).

Table 3.2 – Break-down of production cost for former Piyush

Based on a production cycle in which 2500 bottles are produced		***Quantity***	***Unit Cost***	***Tot. Cost***	***Specific Cost***
		Unit/cycle	***NRs/unit***	***NRs/cycle***	***NRs/bottle***
Manufacturing cost				**602**	**0.24**
Water	L	150.0	2	300	0.12
Bleaching powder	kg	3.0	34	102	0.04
Labor	day	1.0	200	200	0.08
Bottling cost				**12,838**	**5.14**
Bottling components	#	2550	4.25	10,838	4.34
Labor	day	10.0	200	2,000	0.80
NET PRODUCTION COST				**13,440**	**5.38**
NET PRODUCTION COST (in US$[4])				**179.20**	**0.072**

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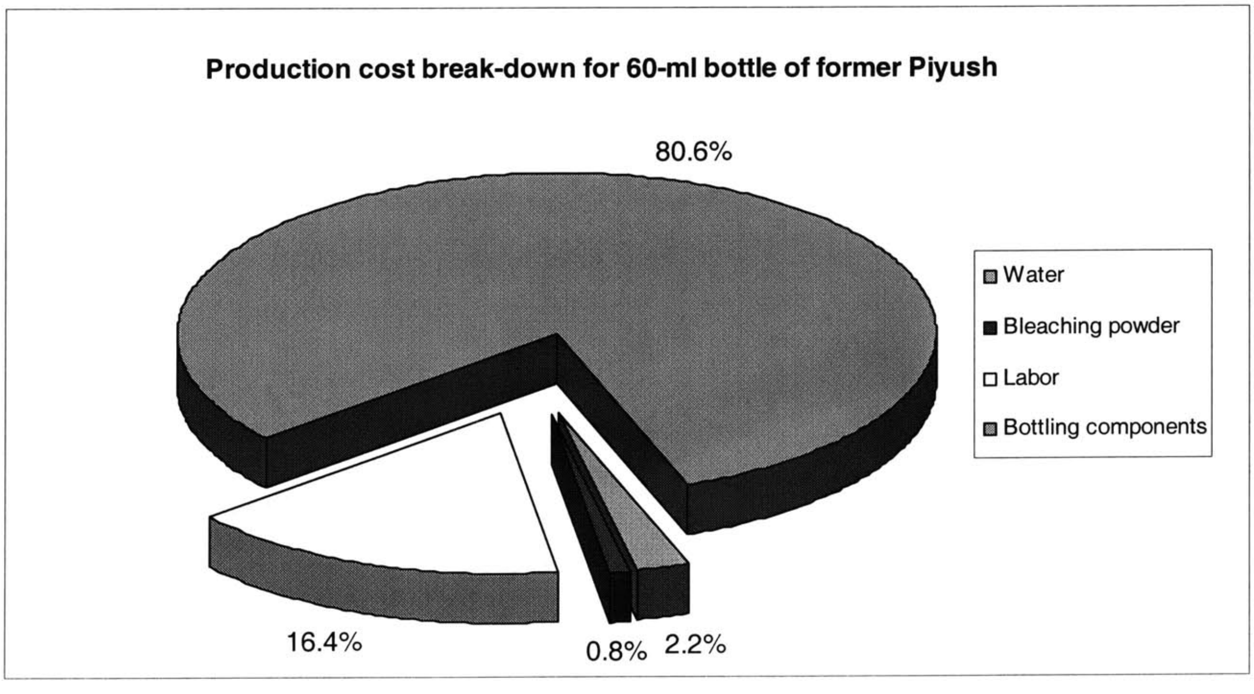
[4] In January 2002, US$ 1 = NRs 75.

Among the manufacturing costs, the cost for producing distilled water was the most difficult to estimate, since the consumed amount was a small part of what ENPHO was producing daily for the laboratory activity. Moreover, the use of distilled water is not strictly necessary. Therefore, in Table 3.2, water cost is simply assumed equal to the supply cost (NRs 2 per liter), which is the price ENPHO pays to the water supplier who delivers water when the public system is not working, and the added cost for demineralization is assumed negligible. The cost of NRs 34 per kg of bleaching powder is what ENPHO was used to pay to the wholesaler. As far as the labor is concerned, according to the ENPHO's technician in charge of the process, one day was sufficient to provide all the materials and prepare the solution, which was then left overnight for settling. Given these assumptions, the total manufacturing cost with the former process is NRs 602 per cycle (equivalent to NRs 4.3 per liter or NRs 0.24 per bottle).

To assess the bottling cost, bottling components' prices and labor are assumed the same as in the new process (see Section 5.5.2). Bottling time has been estimated at 10 days for 2,500 bottles and the wage for unskilled labor paid by ENPHO is NRs 200 per day. Therefore, the total bottling cost is NRs 12,838 per cycle (equivalent to NRs 85.6 per liter or NRs 5.14 per bottle).

Figure 3.1 – Production costs breakdown for a 60-ml bottle of former Piyush



The total production cost for the former Piyush is NRs 5.38 per bottle. The difference between the calculated and the actual cost reported by ENPHO (NRs 10.0) can be considered as an estimate of the overhead fixed cost for the organizational aspects of the production and the salary of the technician in charge of Piyush production.

3.5 Former Piyush production data

Piyush was distributed in two different forms: in 60-ml bottles (see more details in Section 5.3) or as bulk solution, in containers of different size (typically 10- or 20-liter tanks) according to availability or customer request. Production of both forms has been irregular, as shown by the statistics in Table 3.3, since ENPHO did not have a scheduled production plan: Piyush was produced when required for specific purposes, or when new bottles were required from the distribution wholesaler.

Figure 3.2-3 show the monthly production of Piyush, in both forms and as total amount of solution (in liters), assuming each bottle to have exactly a 60-ml content.

Table 3.3 – Statistics of former Piyush production

Production	***Bottles (60 ml)***	***Bulk solution (liters)***	***Total (liters)***
Total (in 40 months, from Sept. 1998 to Dec. 2001)	58,783	3,249	6,776
Monthly average	1,470	81	169
Standard deviation	1,406	243	281

Figure 3.2 – Monthly production of former Piyush as bottles

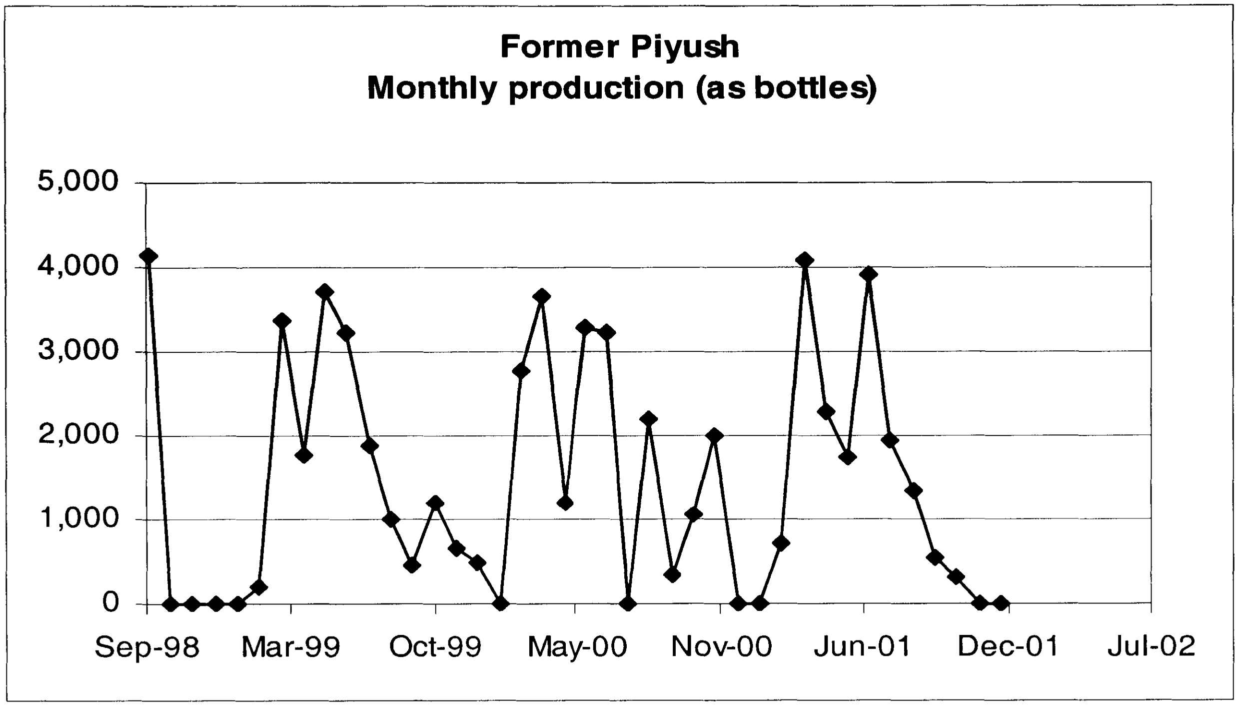


Figure 3.3 – Monthly production of former Piyush as bulk solution

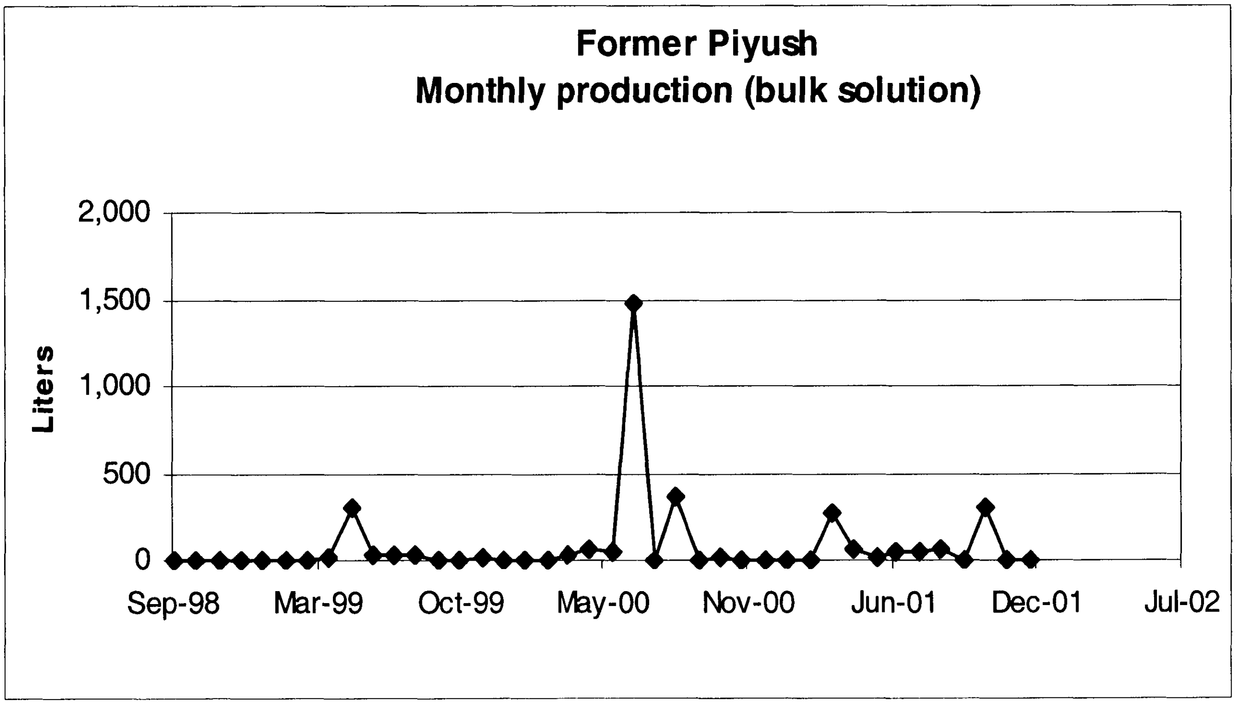
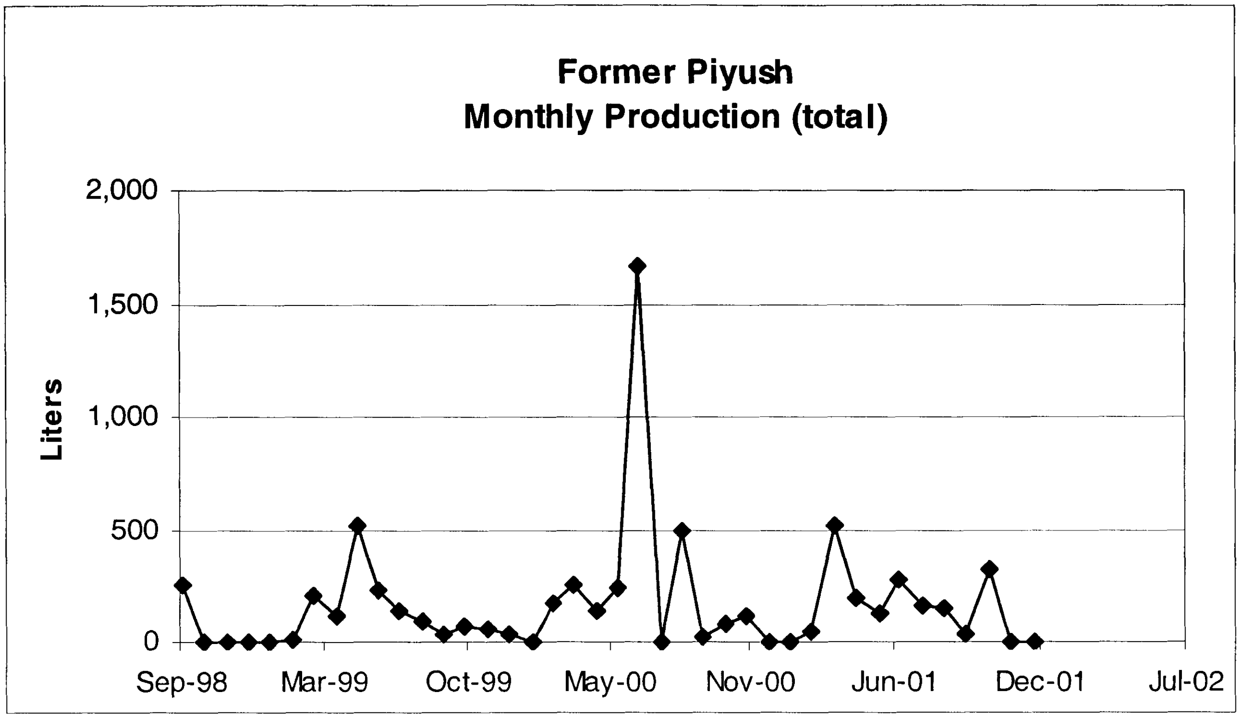


Figure 3.4 – Monthly total production of former Piyush



4. The sodium hypochlorite generator

This chapter describes the sodium hypochlorite generator that ENPHO personnel and the author set up at ENPHO's laboratory in Kathmandu, Nepal, in January 2002. Installation, use, and maintenance instructions provided by the manufacturer are summarized and expanded based upon the experience gained on the site. In addition, the tests used to check the performances of the generator and the quality of the disinfectant solution produced are described.

4.1 Description of the equipment

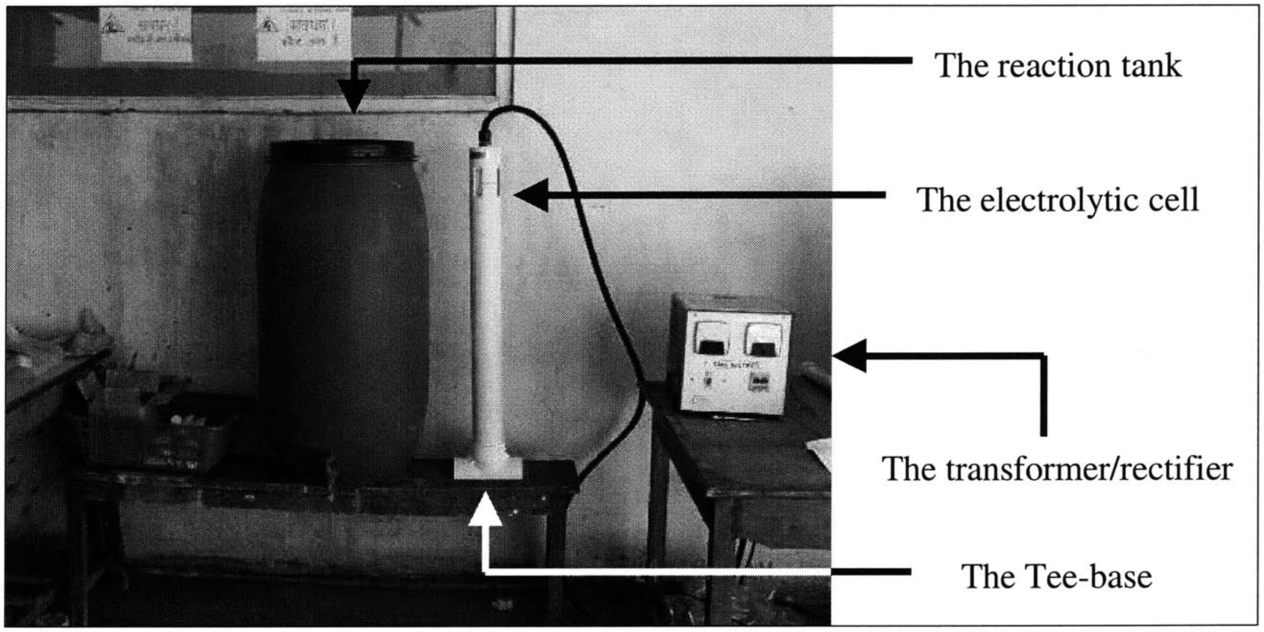
The hypochlorite generator installed at ENPHO is a SANILEC-6, which was donated to the MIT Nepal Water Project team by Severn Trent De Nora in October 2001. The SANILEC-6 unit produces sodium hypochlorite solution through the electrolysis of a brine solution of water and common salt (sodium chloride). The unit produces up to 2.7 kg of available chlorine with a concentration between 0.5 and 0.8 % in a 24-hour production cycle.

The SANILEC-6 unit was chosen for on-site sodium hypochlorite generation in Nepal on the basis of van Zyl's recommendations (Van Zyl, 2001). She identified this unit as preferable to other similar ones, for the following main reasons:

- Safety: the chlorine solution produced is at such a low concentration that is not considered a hazardous chemical. No toxic chlorine gas is produced. Safety measures are minimal.
- Simplicity: the system is simple to operate and requires minimal personnel training and maintenance.
- Flexibility: it can be operated intermittently, when new chlorine solution is needed.
- Mobility: the unit is portable and the sodium hypochlorite can be produced everywhere water, salt and electricity (from the grid or solar panels) are available.

The equipment includes an electrolytic cell, a cell cap, a Tee-base, a transformer / rectifier, and the instruction manual. The electrolytic cell components are a PVC cylindrical case resistant to hypochlorite solution, and two embedded titanium electrodes. When the cell is connected to a power source, the electrodes create an electric field inside the brine solution, which drives the chloride anions to the anode, and the hydrogen cations to the cathode, resulting in formation of chlorine and hydrogen, as described in Section 2.5.

Figure 4.1 – The SANILEC-6 sodium hypochlorite generator



For electrolysis to occur, a continuous current is required. This is provided by the transformer/rectifier, which can be connected either to a 110 or 220 V power socket, or by continuous current sources such as batteries or solar panels.

Once the equipment has been properly installed and tested, the generator is very simple to handle: the operator has to prepare the brine solution in the reaction tank, sink the cell in it and give power to the unit. After a certain amount of hours, which depends on the targeted sodium hypochlorite concentration and the quantity of solution to produce, the reaction is completed, the unit can be shut off and the produced solution bottled. During the production cycles, carbonate salts naturally occurring in hard water can scale the electrodes. Therefore, to avoid a decrease in the performance, a cleaning procedure has to be performed on a regular basis.

4.2 The installation procedure

Between January 7th and 11th 2002, the author collaborated with ENPHO in the installation phase of the new hypochlorite generator SANILEC-6.

The main steps of this phase were:

a) Provide appropriate placement of the unit;
b) Provide a source of water;
c) Provide a safe wastewater drain;
d) Provide a source of energy;
e) Identify and implement safety measures;
f) Procure production cycle accessories;
g) Provide salt;
h) Conduct experimental production cycles to test the generator performance and identify the correct settings.

For each step a description, a rationale and suggestions are given in the following paragraphs.

4.2.1 Placement

In terms of placement, the hypochlorite generator requires a modest amount of space (3x3 meters is sufficient), ventilation, shelter against sun, near-by sources of water and electricity, and a chemically resistant floor. Depending on local conditions, it might be advisable to put the unit in a room with a locker, to avoid theft.

Ventilation is essential since flammable hydrogen gas is produced in the hypochlorite generation process. Constant air exchange ensures that operators are not exposed to high hydrogen gas concentrations and that the ignition threshold is not reached. In addition, safety signs forbidding smoking in the area are mandatory.

The area designated as the hypochlorite production site should be protected from direct sunlight. In fact, hypochlorite will decay rapidly if exposed to light and excessive heat. Even if thick and opaque tanks are adopted, it is likely that hypochlorite will degrade if it is produced and stored for long periods under direct sunlight.

The specific solution adopted in Kathmandu that allowed us to fulfill all these requirements was to place the hypochlorite generator under a porch on the terrace at the top of ENPHO's building. A corrugated iron roof protects the working area from the sun, while ventilation was naturally available. The concrete floor was not affected by accidental hypochlorite spills, and the access to the terrace, situated at the fourth story of the building, was impossible for intruders.

4.2.2 Water source and waste water drain

Depending on the quantity of hypochlorite solution produced, a significant amount of water is needed in the process. Transporting large quantities of water is troublesome and time consuming. Therefore, having a water source next to the working area is a major factor when deciding where to install the unit. In addition to sufficient and reliable production, the water source should have low turbidity and low hardness. Turbidity effects the quality of the hypochlorite solution, while hardness promotes quicker scaling and thus requires more frequent cleaning.

Water available at ENPHO comes both from the municipal water supply and from water trucks, when the public supply is unavailable. In both cases, hardness and turbidity were generally low, as reported by ENPHO, and, therefore, no pretreatment was adopted for this water. Both sources of water were not chlorinated, as proven by residual chlorine tests conducted by the author. A tap connected with a water tank placed on the same terrace was installed in the working area to provide water.

An important feature of the working area created at ENPHO was a safe water drain. The terrace had rain drains that discharged water in the open environment. Since it was likely that these drains would be used to discharge water containing hypochlorite, it was considered important to avoid accidental contact of people with this water. Therefore, a drainage pipe was installed to divert the wastewater from the terrace to the main sewage system of the building.

4.2.3 Source of energy

ENPHO's building is connected to the public electricity supply system of Kathmandu (220 V, 50 Hz). Even if blackouts occur occasionally, especially during rainstorms, this source is considered reliable enough. A power socket, derived from the grid of the building, was installed close to the generator.

The possibility of installing solar panels was considered, but the large surface required and the high investment needed for implementing the system made this solution unviable. More details are given in Section 5.5.4.

4.2.4 Safety measures

Specific attention was paid to ensure proper safety conditions for the operators. The sodium hypochlorite solution produced by SANILEC-6 is at low concentration and, therefore, it poses a minor threat to health. Nevertheless, in case of accidental contact with skin or eyes, it is important to rinse immediately to avoid skin burns and irritation. To allow immediate rinsing, a tap was installed a few meters away from the unit and warning signs were posted close to the reaction tank.

In addition, electric shock can result from improper use of the unit. Therefore, the grounding of the electric line was ensured and warning signs were placed next to the transformer/rectifier.

Appendix E reproduces the "Precautions" sheet that the author prepared for ENPHO, including main use and safety recommendations for operation of the hypochlorite generator.

4.2.5 Production cycle accessories

Lastly, once the working area was ready and water and power source were provided, ENPHO personnel and the author procured the other necessary materials for running the hypochlorite production cycle, such as a reaction tank, buckets for filling the reaction tank and salt for preparing the brine solution.

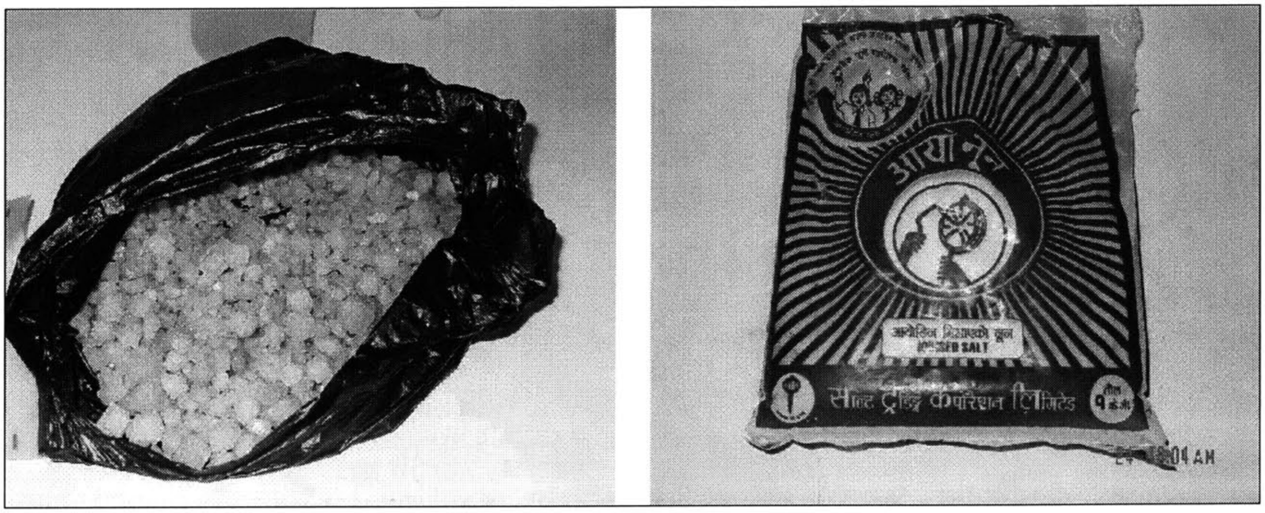
The SANILEC-6 unit requires a reaction tank of 90 cm at least in height. As explained in the instruction manual, during the hypochlorite generation process, hydrogen gas and chlorine are formed within the electrolytic cell case. Hydrogen gas is vented to the atmosphere through two slots placed at the top of the cell. These slots also allow the chlorine rich solution inside the cell to circulate out of the cell case, while fresh brine solution is sucked inside from the bottom. This spontaneous circulation ensures that the whole brine solution in the tank reacts and is transformed into hypochlorite solution. For this process to occur, it is indispensable that the water level in the tank reaches the circulation slots, without, however, submerging them completely. As a consequence, the water level in the tank is restricted to the interval between 80 and 85 cm, where the circulation slots are, and therefore the total height of the tank has to be 90 cm or higher.

A 90 cm tank was available at ENPHO (thanks to a donation of Bhikkhu Maitri from the International Buddhist Society) and thus was used as the reactor tank. The volume of water that reached an 85 cm water level was 150 liters. A plastic spigot was then installed at 5 cm from the bottom. About the other equipment (buckets, storage tanks, lids, stirrer), it is important to point out that they have to be made of PVC or other corrosion-resistant material, since otherwise the hypochlorite solution would corrode them quickly, deteriorating the purity of the hypochlorite solution.

4.2.6 Salt

Salt available in Nepal is of two kinds: granular raw salt and grounded iodine-enriched salt. The granular salt had some soil particles and impurities trapped inside the grains, which could effect the quality of the hypochlorite solution produced. Therefore, ENPHO personnel and I decided that if granular salt was used, settling and filtering of the brine solution had to be performed, as described in Section 4.3.2. Iodine-enriched salt, in contrast, was purified and easier to dissolve, and resulted in a clearer brine solution. However, iodine-enriched salt costs NRs 9 per kg (US$ 0.12) against NRs 6 (US$ 0.08) for granular salt. More detailed economic considerations of the cost of salt are reported in Section 5.5.2.

Figure 4.2 – Raw granular salt and refined iodine-enriched salt



In addition, we wondered whether the iodine present in the iodine-enriched salt would be transferred into the hypochlorite solution during the manufacturing process, resulting in iodination of drinking water. The calculation in Table 4.1 shows that iodine concentration in the water disinfected with hypochlorite is negligible.

Table 4.1 – Calculations to determine iodine content in hypochlorite solution

Quantity to be calculated	***Symbol***	***Equation***	***Value***
I_2 concentration in the salt (as stated on the salt bag)	CI_{salt}	-	50 ppm = 50 mg of I_2 per kg of salt
Salt dose in the manufacturing process (per liter of solution):	D_{salt}	-	30 g/L
I_2 concentration in the hypochlorite solution:	$CI_{solution}$	$= CI_{salt} \times D_{salt}$	1.5 mg/L
Suggested hypochlorite dose (per liter of drinking water):	$D_{solution}$	-	3 drops per liter = 0.15 mL/L
I_2 concentration in drinking water	CI_{water}	$= CI_{solution} \times D_{solution}$	0.225 µg/L

Since the minimum daily iodine intake, recommended by the World Health Organization, ranges from 50 to 200 µg, depending on age and status of pregnancy (WHO, 1994), it was evident that a 0.225 µg/L intake of iodine through water disinfected with hypochlorite solution would not be sufficient to be either a benefit or a detriment to health.

4.3 The production procedure

After the installation phase was complete, a series of three trial hypochlorite batches was produced to assess the generator performance and the variables influencing it, such as salt quantity and cycle duration.

The final version of the production procedure, a result of the experiments conducted in the testing phase, is explained below. A synthesis of the procedure, as adopted by ENPHO, is presented in Appendix C.

The complete hypochlorite production procedure includes the following main phases:

a) Planning the production cycle;
b) Preparing the brine solution;
c) Running the production cycle;
d) Testing for the available chlorine concentration of the bulk solution;
e) Bottling;
f) Testing for the available chlorine concentration of the bottled solution.

4.3.1 Planning the production cycle

A proper planning of the hypochlorite production cycle is important to save time and money. If materials are provided in the required amount and if the phase duration is scheduled properly, the production cycle can be run with minimum personnel requirement and with high time efficiency.

The main steps of the planning phase are:

1. Assess the amount of hypochlorite solution to be produced and the hypochlorite concentration required.

2. Determine the needed amount of water. This amount is theoretically equal to the required amount of hypochlorite solution, since the loss of water in the hypochlorite generation reaction is negligible. However, during the brine preparation phase, the bottling

phase and the testing phase, a significant quantity of liquid is usually lost due to improper handling, leakage and spills; therefore, the total volume of water to be processed should be 3-5 % more than the intended final volume of hypochlorite solution. For example, if 400 L of hypochlorite solution is required, the total water to be processed should be 420 L, which gives a 5 % margin.

3. Determine the number of production cycles to be run. The total volume of treated water has to be compatible with the volume manageable by the hypochlorite generator in a single production cycle. Since the reaction tank has to be filled to the height of the circulation slots on the generator, about 85 cm from the bottom, as discussed in Section 4.2.5, the volume of water that can be treated in a single cycle depends only on the diameter of the tank. For example, if a cylindrical tank with a diameter of 48 cm is used, as is the case in our setup at ENPHO, the water volume that can be treated in one cycle is:

$$V_{cycle} = (D/2)^2 x\ H = (0.48\ m / 2)^2\ x\ 3.14\ x\ 0.85\ m = 0.153\ m^3 = 153 \text{ liters}$$

where:
D is the diameter,
H is the height of the circulation slots on the generator.

If the tank is not cylindrical, the volume that allows water to reach the generator circulation slots has to be determined experimentally.

When a hypochlorite volume larger than what can be produced in a single cycle is needed, more cycles have to be performed. The number of production cycles required is calculated by dividing the total hypochlorite volume to be produced by the capacity of the tank, rounded to the next highest whole number. In symbols:

$N = \text{int}\,(V_{tot}/V_{cycle)}) + 1$ *Equation 4.1*[5]

where:

N = number of production cycles;

V_{tot} = required volume of sodium hypochlorite (already increased by 3-5%);

V_{cycle} = the volume of sodium hypochlorite that can be produced in a single cycle;

int is the function which selects the integer value of the ratio $V/V_{cycle.}$

Referring to the previous example, if the total volume of hypochlorite solution required is 420 L and a 150 L tank is available, 3 cycles have to be run (420 L / 150 L = 2.8 → rounded to the next highest whole number gives 3). The actual amount of hypochlorite solution produced can be higher than the required amount, due to the rounding. In this example, 3 cycles of 150 liters each are planned, with a total production of 450 liters of hypochlorite solution, instead of the required 420 liters. However, this can not be avoided, since 2 cycles would not be sufficient, and each production cycle must be run with a water volume of 150 liters to comply with the compulsory water level in the reaction tank).

4. Determine the amount of salt to be purchased. The amount of salt required in the hypochlorite generation process is proportional to the quantity of solution to be produced, with a coefficient (R_s) equal to 30 g per liter of water. Therefore, the amount of salt needed per production cycle is given by the following formula:

$S_{cycle} = R_S \times V_{cycle}$ *Equation 4.2*

where:

S = amount of salt to be used in one cycle (kg),

R_S = ratio between salt and water (0.030 kg of salt/L),

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[5] Equation 4.1-4 are implemented in the "Production cycle" EXCEL spreadsheet of the file PIYUSH.XLS on the companion floppy disk. The spreadsheet is also reproduced in Appendix H.

V = volume of water to be used in each cycle (L).

The total amount of salt to be purchased to produce the required volume of hypochlorite solution results from the product of the number of cycles to be performed and the amount of salt needed in each cycle:

$S_{tot} = N \times S_{cycle} = N \times R_S \times V_{cycle}$ *Equation 4.3*

where: N = planned number of cycles to be run.
Continuing with the previous example, a 150-liter production cycle requires 4.5 kg of salt, and 3 cycles require a total of 13.5 kg salt.

5. Determine cycle duration and schedule. The duration of a production cycle is proportional to the volume of water treated, and the theoretical factor suggested by the manufacturer is 8.9 hours per kg of available chlorine to be produced. However, salt quality, water quality, and generator electrode conditions far from the ideal case may determine a different value. In addition, in Nepal it was observed that if the current in the electrolytic cell is lower than the theoretical value of 55 A indicated by the manufacturer, a longer cycle is necessary to reach the targeted concentration. A correction factor for the actual current is included in the formula for calculating cycle duration:

$T = M_{tot} \times R_T \times F_C$ *Equation 4.4*

where:
T = cycle duration time (h);
M = quantity of available chlorine to be produced (kg);
R_T = ratio between cycle duration time and available chlorine quantity (h/kg);
F_C = the correction factor for the current (-), and it is equal to the ratio of the actual current and the theoretical expected current in the electrolytic cell (55 A).

In the trials performed between January 9th and January 18th 2002, the actual ratio between cycle duration and available chlorine in the solution was determined to be 9.5 h/kg. The output current of the transformer/rectifier was always about 25 A. Therefore, in order to produce 150 liters of hypochlorite solution, with an available chlorine concentration of 5.3 g/L (0.53 %), the duration of the production cycle was determined to equal 16.6 h.

$$T = (150\ \text{L} \times 5.3\ \text{g/L} / 1000\ \text{g/kg}) \times 9.5\ \text{h/kg} \times (55\ \text{A} / 25\ \text{A}) = 16.6\ \text{h}.$$

Scheduling the production cycles is useful when these are longer than the typical working day (7-8 hours). In this case, in fact, the chlorine generator can be run overnight, when no personnel activity or supervision is required, while the day time can be used to prepare the brine solution and to test and bottle the freshly produced hypochlorite solution. In this way, subsequent cycles can be run one each day, optimizing personnel time.

4.3.2 Preparing the brine solution

The brine solution is the solution of water and common sodium chloride salt that is transformed into a solution of sodium hypochlorite by the hypochlorite generator.

Preparing a clear brine solution is important for two reasons: first, impurities in the solution might foul the electrolytic cell and affect the generator performance; secondly, brine solution turbidity is transferred into the hypochlorite solution, giving a poor aesthetic quality to the final product.

To avoid turbidity in the brine solution, clean equipment and good quality salt and water must be used. The quality of the water is obviously fundamental. Microbiological contamination, although not desirable, is not of concern, since bacteria will die as soon hypochlorite is formed at increasing concentrations in the reaction tank. In contrast, chemical contamination due to metal ions (iron, manganese, arsenic, etc.) or organic matter has to be avoided, as these compounds stay in the hypochlorite solution, which is ultimately added to drinking water. In general, the raw water used in the hypochlorite process should be drinkable in terms of chemical contamination or presence of organic matter.

As far as the salt is concerned, if it is not refined and comes in grains containing soil and sand particles, brine solution should be treated before starting the hypochlorite generation process. Two possible easy treatments are settling and the filtering the solution through a cloth. Settling consists in dissolving salt grains in a bucket and waiting 30-60 minutes before pouring the supernatant into the reaction tank, allowing the greater part of the sand to settle to the bottom of the bucket. To filter the brine solution, mount a cloth on the mouth of the reaction tank and slowly pour the settled brine solution through it, in order to capture the finest soil particles.

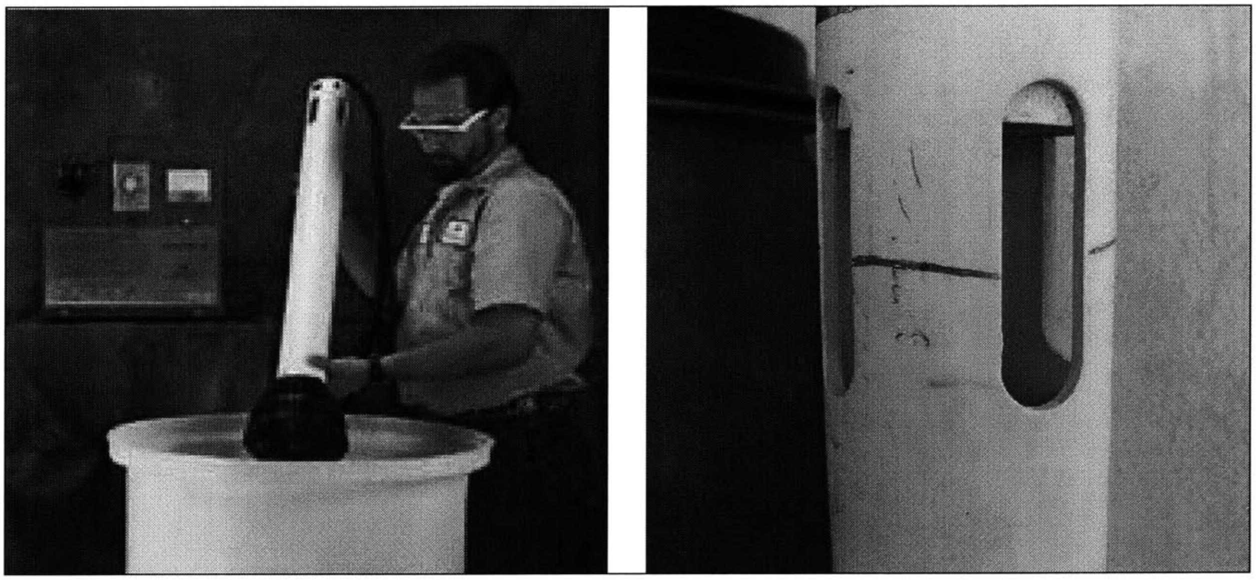
The steps involved in preparing the brine solution are summarized as follows:

1. Wash the equipment involved in the hypochlorite process (the generator, the reaction tank, the tank spigot, the stirring stick, and the buckets used for dissolving the salt and filling the reaction tank);
2. Pour part of the total required amount of salt in a bucket and fill with a known amount of water;
3. Stir the solution till the salt has been completely dissolved and remove supernatant impurities;
4. Allow the solution to settle, if necessary;
5. Transfer the cleared solution to the reaction tank, filtering through a cloth if necessary;
6. Repeat Steps 2 to 5 untill the whole amount of salt required for a cycle is in the tank;
7. Fill up the reaction tank with water to the required volume.

4.3.3 Running the production cycle

This phase consists in placing the hypochlorite generator in the reaction tank, setting the timer and starting the hypochlorite generation process. When placing the generator in the brine solution, check that the water level is between half way and the top of the circulation slots. Be sure that the circulation slots are not completely submerged. The tee-base at the bottom of the generator is intended to support it in the reaction tank, but it is not necessary for the generator to stand completely vertical during operation. The generator may lean to one side without causing any decrease in production.

Figure 4.3 – The electrolytic cell and the circulation slots



After placing the generator in the reaction tank, energize the transformer/rectifier by turning the circuit breaker to the ON position. Then, set the timer at the required cycle duration, pressing the blue arrow keys on the timer panel. Hypochlorite generation begins by pressing the RESET bottom. The electrolytic cell is energized and hydrogen gas begins bubbling out from the circulation slots. The current and voltage readings shown on the front side panel of the transformer/rectifier should be periodically checked. They should remain constant during the whole cycle.

The generator shuts off automatically after the cycle time is complete, without the need for continuous supervision by personnel. At the end of the cycle, turn the circuit breaker to the OFF position, disconnect the transformer/rectifier from the AC power source, extract the generator from the reaction tank and rinse it. To better preserve the freshly produced hypochlorite solution, the tank should be closed with a thick opaque plastic lid.

4.3.4 Testing available chlorine concentration in the bulk solution

The freshly produced hypochlorite solution can be tested for available chlorine content using one of the various methods reported in Standard Method for the Examination of Water and Wastewater (1998) or other specific methods indicated by chemical supply companies. For example, iodometric titration is usually sufficiently accurate to determine the available chlorine concentration in the expected range [0.5 - 0.7] %.

If the actual concentration of sodium hypochlorite is lower than the targeted concentration (ex. 0.45 % instead of 0.50 %), the generator should be run for a longer time, untill the targeted concentration is reached. In contrast, if the actual hypochlorite concentration is higher than the targeted value, it can be reduced by dilution. The amount of water to be added can be calculated using the following formula:

$$X = (C_0 / C_t - 1) \times V_0$$ *Equation 4.5*

where:

X = amount of water to be added (L),

C_0 = actual available chlorine concentration (mg/L or %),

C_t = targeted available chlorine concentration (mg/L or %, consistent with C_0),

V_0 = actual volume of solution (L).

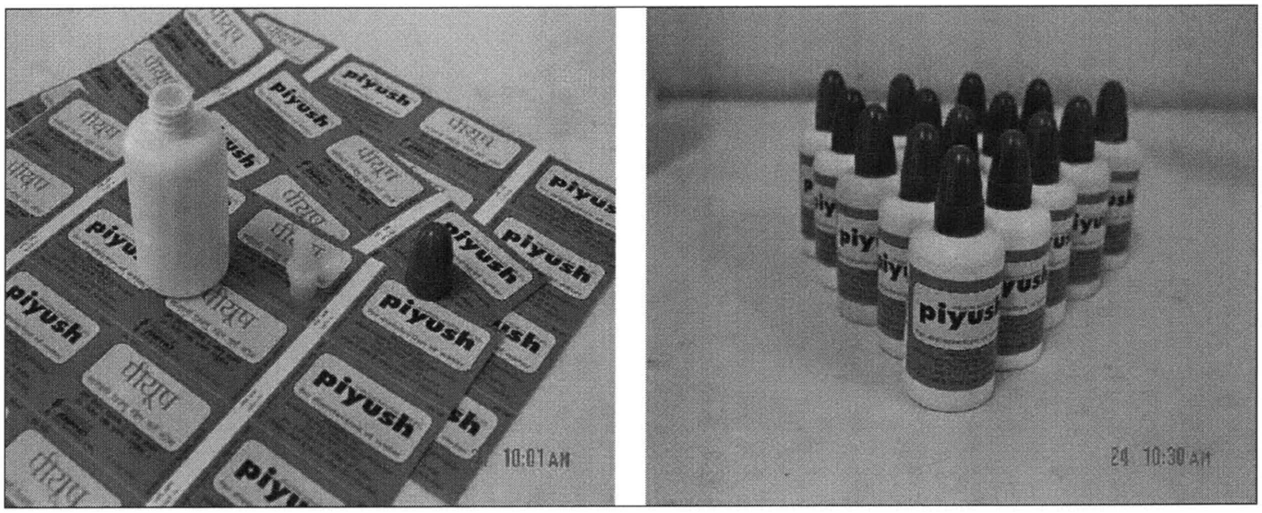
4.3.5 Bottling

Bottling is the most time and labor intensive step. A spigot with a mouth size adequate to fit the intended bottleneck should be used in order to make bottle filling as easy and quick as possible.

The bottles or the other containers used to store or sell the hypochlorite solution must be clean and opaque, to avoid decay of the hypochlorite by light. Bottles with thin and transparent walls (the liquid level can be easily seen inside) must not be used. Multiple transfers from the reaction tank to other containers are likely to contaminate the hypochlorite solution and to reduce its available chlorine content.

Once bottles are filled, the dosing nozzle can be inserted and the dosing hole punched on it. It is highly recommended to adopt a standard method for producing the hole, for example, always using the same needle, to have consistent dosing from every bottle. The last step is to put on the cap and attach the label on the bottle.

Figure 4.4 – Piyush bottling components and some complete Piyush bottles



4.3.6 Testing available chlorine concentration in the bottled solution

The bottling process can cause loss of available chlorine, due to dirt in the bottles or excessive aeration. Testing for available chlorine in the final product is advisable, using samples from a significant number of randomly chosen bottles and the same available chlorine testing method already used for the bulk solution (see Section 4.3.4). Fifteen bottles should be tested to achieve a precision of ± 200 mg/L with a 95% confidence level, if the standard deviation of the concentration is about 400 mg/L (see Appendix G for the calculations)

4.4 The cleaning procedure

During the sodium hypochlorite process, the electrodes inside the electrolytic cell are scaled with calcium carbonate and other insoluble salts that form due to the hardness of natural water. Therefore, a periodical cleaning is required, in order to avoid excessive scaling, which would lower the electrical efficiency of the generator.

To remove scale, the electrolytic cell has to be soaked in an acetic or hydrochloric acid solution. A solution of 5% acetic acid is preferred since it is not dangerous for operators. These can be replaced with common vinegar, which is likely to be readily available in developing countries. The soaking time using vinegar or 5% acetic acid is 1 hour, divided in two cycles of

30 minutes (soak, rinse and change solution, soak again). The amount of cleaning solution is 3.8 liters (1 US gall) per cycle. The cleaning procedure should be performed at least once a week, if the generator is used daily. Appendix D provides the detailed list of steps for the operators.

4.5 Production process tests

Between January and April 2002, the author carried out several tests to assess the performance of the new production process and the quality of the sodium hypochlorite solution produced. Main objectives of this phase were:

a) Determine the relationship between the parameters of the production cycle (duration, product chorine concentration, water, salt and energy consumption);
b) Check the stability of the solution before bottling;
c) Check the quality consistency of the solution after bottling;
d) Check the quantity consistency of solution after bottling;
e) Check for stability of the solution after bottling.

4.5.1 Materials and methods

Two HACH Company test kits and corresponding methods were used. Method 8209 (Iodometric Method Using Digital Titrator) was used to determine the concentration of available chlorine in the sodium hypochlorite solution produced by the generator. This method can be applied for solution with an available chlorine content in the range 0.2-7.0 % and is equivalent in principle to the Iodometric Method I reported by the *Standard Methods for the Examination of Water and Wastewater* (1998).

Method 10069 (DPD Mehod) was used to measure the free residual chlorine in water samples disinfected using the freshly made sodium hypochlorite (range of free chlorine 0-5 mg/L). This method is adapted from the DPD colorimetric Method in SMEWW.

Occasionally, ENPHO technicians conducted duplicate analyses. The SMEWW Iodometric Method I was adopted to measure the total chlorine concentration in the pure sodium hypochlorite solution, while test kit, based on the orthotolidine method and manufactured by ENPHO[6], was used for free residual chlorine measures.

4.5.2 Determining the characteristics of the production cycle

Following the manufacturer instruction manual, three 150-liter batch of sodium hypochlorite solution were prepared, with the characteristics reported in Table 4.2:

Table 4.2 – Characteristics of the batches

Batch #	*Date*	*Salt (kg)*	*Cycle duration (h)*	*Current (A)*	*Final available chlorine conc. (%)*
Batch 1	1/8/02	3.0 (granular)	5.5	14	0.11
Batch 2	1/9-11/02	4.5 (refined)	16.5	25	0.53
Batch 3	1/16/02	4.5 (granular)	17.5	25	0.56

Batch 1 did not reach the targeted available chlorine concentration of 0.5 % and therefore was discharged. Three reasons were given for this result: first, the salt was less than the required quantity of 0.03 kg/L of water (a significant loss probably was caused while salt was rinsed to remove sand and soil particles); second, the current was too low (14 A instead of the theoretical value of 55 A); last, the duration of the cycle was too short (5.5 hours). At the time of this first batch, it was not clear yet that the hypochlorite concentration could be increased by just adding more salt and running the generation cycle longer, as was discovered in the following experiments.

Then, batch 2 was prepared and a production cycle of 7 hours was run. At the end of this period, the concentration of the hypochlorite was lower than the targeted value of 0.5 %. Chloride concentration was measured (15,000 mg/L), showing that a large part of the chloride ions in the brine solution had not reacted yet. Therefore, the production cycle was extended until

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[6] The orthotolidine method was included in the SMEWW, 1965 edition, and possibly few other following editions, but it is now considered obsolete because of the hazard to people making the powder and the solution, which are potentially carcingen to human bladder and the urinary tract. Its use in USA is likely to diminuish and eventually disappear in few years (White, 1999).
The test kit prodcuced by ENHO includes two glass test tubes and the ortotholidine solution. 3 drops are added to the water sample and the resulting yellow color, which indicates free chlorine presence, is compared to a colorimetric scale printed on the kit box.

the target concentration of 0.5 % was reached after 16.5 hours. The available chlorine concentration values and the correspondent cycle duration are listed in Table 4.3.

Table 4.3 – Concentration of available chlorine vs. cycle duration

Time (h)	0.0	7.0	9.0	11.0	16.5
Conc. (%)	0.00	0.26	0.31	0.37	0.53

Figure 4.5 – Concentration of available chlorine vs. cycle duration

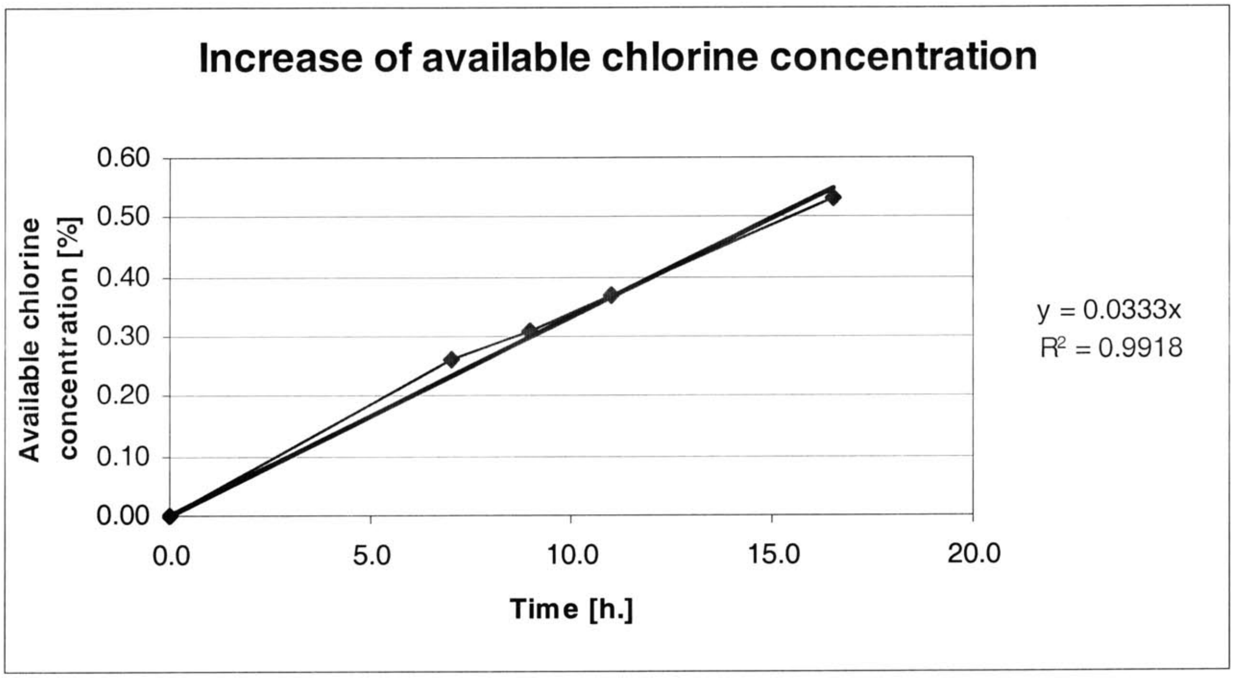


Figure 4.5 shows the increase of available chlorine concentration with the extended duration of the cycle. Through a linear regression analysis of the data, an actual factor of 0.0333% of available chlorine increase per hour was determined, and a cycle total duration of 15.5 h was fixed to reach the available chlorine concentration of 0.50%.

The theoretical duration according to the manufacturer is about half of this value (8 h). The explanation put forward in Nepal and then confirmed by the manufacturer is that delay in the process is due to the current intensity, which was less than half of what was expected (25 A instead of 55 A). This fact does not affect the overall energy consumption of the unit, but makes cycles longer. A correction factor for the actual current has been included in the formula used to calculate cycle duration.

The correct choice of salt and water quantity was confirmed in the third batch, which had a longer duration (17.5 h), producing a higher available chlorine concentration (0.56%). This value is consistent with the correction factor determined.

4.5.3 Stability of hypochlorite solution before bottling

A portion of the hypochlorite solution produced in Batch 2 on January 11th 2002 was bottled in 60-mL plastic bottles and the remaining stored in 75-liter plastic tanks, protected from direct sunlight and heat.

On January 22nd 2002, the hypochlorite solution stored in one of the 75-liter tanks was tested again and the same concentration of available chlorine previously determined was found (0.53%).

From this we concluded that, if stored in clean tanks properly protected from sun and heat, the sodium hypochlorite solution does not decay in the short period. Therefore, if it is necessary for logistical reasons, the bottling can be postponed at least 10 days without effecting the quality of the product. However, since the tanks are difficult to move and are more prone to be contaminated, the bottling of the solution should be done as soon as possible after completing the test on the available chlorine concentration.

4.5.4 Consistency of hypochlorite solution quality after bottling

Available chlorine concentration in the bottled solution was also measured immediately after the bottling, to check if any loss had occurred in the bottling process. The bottling process is a delicate phase, since the liquid is aerated while it is poured into the bottle and this can produce a loss of chlorine through volatilization. In addition, available chlorine can be consumed if the bottle has not been properly cleaned.

Three bottles were randomly chosen from a group of 20 prepared with hypochlorite solution from Batch 2. The concentrations determined are reported in Table 4.4

Table 4.4 – Available chlorine concentration in three different sodium hypochlorite bottles

Bottle	***1***	***2***	***3***
Conc. (%)	0.50	0.52	0.51

The average chlorine concentration in these bottles is 0.51 % with a standard deviation of 0.01. If compared with the concentration of the hypochlorite bulk solution, which was 0.53 %, these data seem to suggest that a loss of chlorine had occurred.

Applying basic statistical analysis (details are given in Appendix G), the parameters of the normal distribution of the available chlorine concentration in the bottles could be estimated. With a 95% confidence level, the mean of the distribution is in the range [0.49; 0.53] (the % is neglected to avoid confusion), and the standard deviation is lower than 0.04.

A student-t distribution test was used to check if the values determined experimentally could be explained simply as consequence of the variability of the chlorine concentration in the bottles or whether there was evidence of a loss of available chlorine concentration in the bottling process. Assuming a 95% confidence level, the interval in which the available chlorine concentration average can fall is [0.505; 0.555]. Since the value calculated from the samples (0.51%) falls in this interval, there is not statistic evidence that the bottling phase is responsible for a loss of available chlorine. The lower average of the sampled bottles can simply be explained with the random variability between bottles.

However, this loss is likely to occur if the bottles are not clean. In addition, even if sufficient precautions are taken in the bottling process, a random variability in the chlorine concentration inside each bottle is inevitable. This problem is common in the manufacturing of packaged products, and it is usually addressed by quality control procedures, which guarantee transparency for the customers about what they are actually buying.

Depending on the ENPHO policy and the requirements for the registration of Piyush, two different strategies can be adopted. The first strategy is to manufacture the product aiming at a chlorine concentration of 0.50% and then declare this value as the nominal concentration, with a determined variability given by the confidence level adopted. For instance, if a 95% confidence level is adopted, the actual chlorine concentration can be expected to be in the range [0.48; 0.52]. The alternative strategy is to declare that, with a given confidence, 0.50% represents the minimum guaranteed chlorine concentration. In this case, the target concentration in the manufacturing process must be higher than 0.50%, so that the percentage of bottles with a lower concentration does not exceed the level of confidence adopted. For instance, if it is required that not more than 5% of the whole production of bottles show a concentration lower than the nominal concentration of 0.50% (95% confidence level), the target concentration in the manufacturing process must be 0.52% (for the calculation behind the examples reported in this section, see Appendix G).

In conclusion, in order to guarantee reliability of the product, three precautions should be observed in the bottling process:

a) The bottles must be clean. If the bottle manufacturer does not provide sealed packages, bottles should be washed with clean water and then kept in a clean place till dry. The rinsing has to be performed sufficiently in advance to allow drying and avoid dilution of the chlorine solution with residual water from the rinsing.

b) If the second quality control strategy is adopted, the available chlorine concentration of the bulk hypochlorite solution should be higher than the nominal value of 0.50%. A target value of 0.52% is suggested. This precaution will guarantee that if any loss of chlorine occurs in the bottling process, the actual available chlorine concentration will still be greater than 0.50% in 95% of the production.

c) The available chlorine concentration should be regularly tested on a certain amount of randomly chosen bottles. The procedure for determining the number of bottles to be tested is described in Appendix G. For instance, if we want to be sure with a 95% confidence level that the available chlorine concentration is within ±0.02% around the mean value of 0.52%, and the standard deviation of the bottles is 0.04%, the number of bottle to be tested is 15.

Although testing the chlorine concentration of fifteen different bottles might seem troublesome, this is the proper way to provide a reliable product in terms of actual concentration of chlorine. Furthermore, fifteen bottles represent only the 0.6% of the overall production of about 2500 bottles obtainable from a 150-liters tank of solution.

4.5.5 Consistency of hypochlorite solution quantity in the bottles

Consistency of hypochlorite solution quantity in the different bottles was another characteristic to be verified. Twenty bottles were randomly chosen and weighed, in order to measure indirectly the volume of hypochlorite solution. The measurements were performed in a 5-minute interval, during which the temperature could be assumed constant; therefore, density was also assumed constant and the variation of weight was considered directly related to the variation of liquid content.

Table 4.5 lists the measured values. The probabilistic distribution of the weight of full bottles was assumed to be normal with an estimated mean of 61.2 ± 1.0 grams, and a standard deviation in the interval [2.2; 2.9], both determined considering a 95% confidence level.

Table 4.5 – Weight of 60-mL hypochlorite bottles

Bottle	*Weight (g)*	*Bottle*	*Weight (g)*	*Bottle*	*Weight (g)*	*Bottle*	*Weight (g)*
1	61.7	6	57.7	11	61.4	16	57.7
2	56.8	7	63.6	12	62.2	17	61.0
3	61.3	8	65.0	13	59.6	18	59.4
4	61.1	9	62.1	14	64.7	19	62.7
5	62.1	10	60.8	15	61.8	20	60.9

The variability in the weight of the full bottles derives not only from a different content of disinfectant, but also from the variability of the weight of the bottles themselves. To assess this variability, 20 empty bottles were weighted. Values are listed in Table 4.6.

Table 4.6 – Weight of 60-mL empty bottles

Bottle	*Weight (g)*	*Bottle*	*Weight (g)*	*Bottle*	*Weight (g)*	*Bottle*	*Weight (g)*
1	6.1	6	5.8	11	5.8	16	5.5
2	5.6	7	6.2	12	5.8	17	5.8
3	5.8	8	5.8	13	5.7	18	5.7
4	5.6	9	6.0	14	5.7	19	5.7
5	6.5	10	6.3	15	5.9	20	6.2

With a 95% confidence level, the average weight of an empty bottle is in the interval [5.8; 6.0] grams, and the standard deviation is between 0.3 and 0.4 grams.

The parameters from both the distributions (for empty and full bottles) are used to calculate the parameters of the normal distribution of the quantity of solution in the bottles. The average content is the difference between the two means, i.e. 55.3 g, while the standard deviation is given by the square root of the sum of the standard deviation squared (s^2), i.e. 4.9 g.

Since the density of the sodium hypochlorite solution is approximately equal to the density of water (1.0 g/ml) an average weight of 55.3 g implies an equivalent content in mL, which differs from the nominal content indicated on the label (60 mL) by almost 8%. This value has to be compliant with the regulation existing in Nepal. In the case such a value is not acceptable, the nominal content on the label of sodium hypochlorite bottles must be changed.

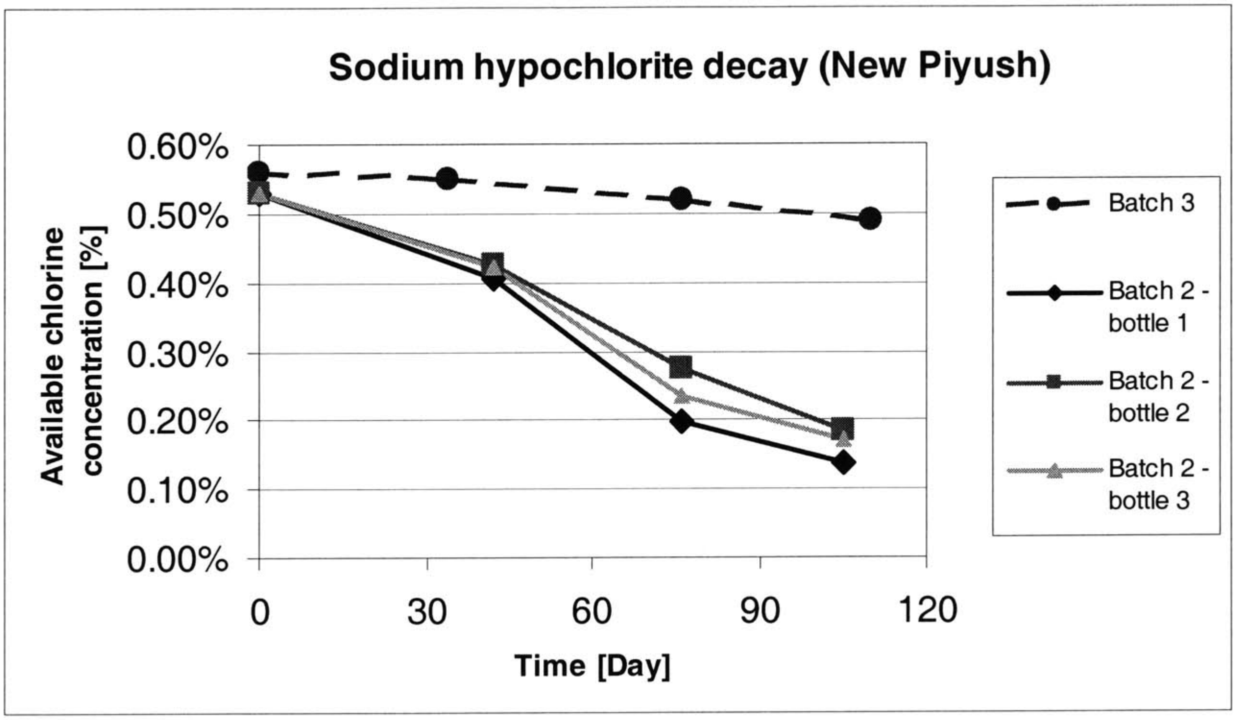
4.5.6 Stability of hypochlorite solution after bottling

Sodium hypochlorite prepared in January 2002 (batch 2 and batch 3) was tested in the following months to check for variation of the available chlorine concentration. Results are listed in Table 4.7 and graphed in Figure 4.6. Sodium hypochlorite from batch 2 was bottled two days after manufacturing and bottles were brought from Nepal to MIT and kept in a dark closet at room temperature. Sodium hypochlorite solution in batch 3 was constantly kept in the dark plastic tank on ENPHO's building terrace. Available chlorine tests on the bottles were conducted using HACH method 8209, while tests on samples from batch 3 were performed by ENPHO, using the iodometric titration method described in the Standard Methods (1998) (see Section 4.5.1).

Table 4.7 – Available chlorine concentration in new Pyush

Concentration of available chlorine (%)					
Batch 2 Initial available chlorine concentration: 0.51%				***Batch 3 Initial available chlorine concentration: 0.56%***	
Time lag (days)	***Bottle 1***	***Bottle 2***	***Bottle 3***	***Time lag (days)***	***Tank***
10	0.50%	0.52%	0.51%	7	0.56%
42	0.41%	0.42%	0.42%	34	0.55%
76	0.20%	0.27%	0.24%	76	0.52%
105	0.14%	0.18%	0.17%	110	0.49%

Figure 4.6 – Decay of the sodium hypochlorite solution manufactured in Nepal

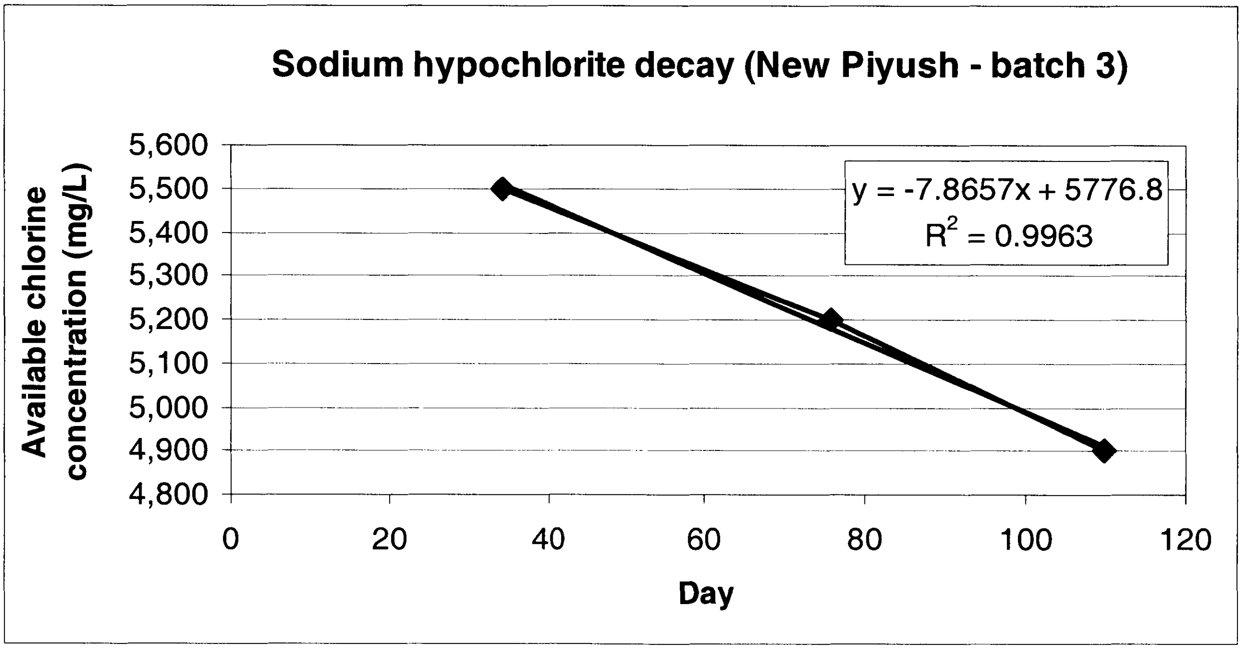


For sodium hypochlorite from batch 2, the calculated half-life parameter is not constant, decreasing from an average of 122.7 days over the first interval to 42.5 days over the second, and 55.5 days over the third period. These variations suggest that the decay process does not have a first order kinetics, in which the half-life parameter is a constant; rather, there is an initial acceleration of the decay process, which slows down afterwards. All half-life values are much lower than reported in literature for 0.5 % sodium hypochlorite solutions (stability over 200 days, Piskin, 1995; half-life of 6000 days, White, 1999). A likely explanation for this phenomenon is offered by the fact that batch 2 was manufactured in a tank with an iron-made spigot, which was found severely corroded when the reaction tank was emptied. Probably, iron ions diffused into the solution because of corrosion and catalyzed the self-accelerating decay process that is described in Section 2.6.

Before manufacturing batch 3, the iron spigot was replaced with a plastic one. Data in the last column of Table 4.7 corresponds to half-life constants of 2068 days, 519 days, and 396 days respectively. These values are higher than in the previous case, and do not show any significant acceleration, supporting the hypothesis of iron-catalyzed decay for sodium hypochlorite solution in batch 2. A linear regression over the last three points reveals a constant average decay rate of 0.023% available chlorine per months (equivalent to the 7.865 mg/L per day value in Figure 4.7). Consequently, starting from an initial concentration of 0.56%, new Piyush available chlorine concentration would drop below the nominal value of 0.50% in 2.5 months.

The validity declared for former Piyush bottles is one year from the manufacturing date (see section 5.4.1). This expiration date is too long for the new Piyush, which in such amount of time would almost halves its available chlorine concentration, and thus the suggested dose would provide insufficient disinfection. Addition of sodium hydroxide (NaOH) might be a solution to raise pH above 12 and slow down the decay process. CDC (2002g), for example, suggests adding 60 g per 100 liters of sodium hypochlorite solution, and indicates a pH between 11 and 12 as the target to ensure stability in warm climates for at least 4 months. In cool climates, such alkalinization ensures stability for more than 6 months. Further investigation on the decay rate of alkalinized sodium hypochlorite is suggested, to assess the real decay rate in this case, and, based on the results, Piyush validity period might need to be corrected.

Figure 4.7 - Decay of new Piyush (Batch 3)



4.5.7 Free Residual Chlorine tests

In January 2002, samples of water from ENPHO's laboratory tap were disinfected with the new 0.5% sodium hypochlorite solution and Free Residual Chlorine (FRC) was measured with HACH method 10069 after half an hour to check if the suggested dose of Piyush produced a FRC level safe for drinking.

In the first series of tests, three drops of 0.5% available chlorine solution were dosed into 1 liter of tap water. The approximate volume of one drop was 0.05 ml; therefore, the FRC was expected to be lower than 0.75 mg/L (this value could be reached only for a chlorine demand of the tap water equal to zero). The actual values ranged between 0.21 and 0.61 mg/L of FRC, showing that the suggested dose is adequate to provide a sufficient FRC level, even if this can be quite far from the target value of 0.20 mg/L. However, all the values were found in the range 0.2-1.0 mg/L, which is commonly accepted for drinking purpose (see last part of Section 2.7). The results also showed that the tap water in Kathmandu's public supply system has a low chorine demand (between 0.14 and 0.54 mg/L).

A second series of tests was conducted at ENPHO with the same disinfectant solution (0.5% available chlorine) and 20-liters samples. Ten liters and twenty liters are typical sizes of the containers used in the Lumbini Chlorination Pilot Project and more generally for water collection and storage in rural areas of Nepal. As reported by Sullivan (2002), the suggested solution dose of 3 drops per liter is not practical for such large volumes, since the number of drops (60) is too high to be counted precisely and takes too much time to dose. A whole capful of disinfectant (3.4 ml) was dosed in a 20-liter bucket, and the FRC level was measured after 30 minutes. The average FRC value was 0.59 mg/L (versus an expected maximum residual of 0.85 mg/L). Even if a capful is about 68 drops, it still provides an acceptable and safe FRC level for the 20-liters size bucket, based on the chlorine demand of this experiment.

Finally, tests with a half cap of disinfectant dosed into 20-liters size buckets were performed. FRC values were below 0.11 mg/L, which is considered too low for safe drinking water. In addition, uncertainty on the dose is given by the fact that a half cap is a highly subjective measure, especially given the shape of the current cap, which does not identify any half point clearly.

In conclusion, a dose of 3 drops per liter of the new 0.5% available chlorine solution was proven to provide a sufficient FRC level in Kathmandu urban tap water with low chlorine demand. For water with similar chlorine demand and a 20-liter volume to be disinfected, one capful can replace the 3-drops-per-liter dosage system. However, more precise information is needed about fresh water chlorine demand in rural areas during different periods of the year, before a universally applicable dose can be suggested. In any case, an improved cap for appropriate dosing to 10 and 20 liter buckets is needed.

5. A Business Plan for Piyush

The goal of this chapter is to put together in a coherent way the information available about the hypochlorite market in Nepal and evaluate the economic feasibility of a micro-enterprise for the production, promotion and distribution of sodium hypochlorite as a solution for household water disinfection. In particular, the main questions this chapter aims to answer are: "Is sodium hypochlorite a viable social[7] business in Nepal? If so, what are the main recommendations for its development in Nepal in the present scenario?"

A Business Plan is the starting point for a new business, since it organizes information and proposes strategies under a coherent logical framework. While recognizing that the author's knowledge of the actual status of resources and constraints for business development in Nepal is quite limited, nonetheless, this chapter attempts to put together a draft Business Plan. Some sections of this Business Plan are intended merely to depict different scenarios and possible solutions, without providing a final recommendation. Chapter 7 includes suggestions as to what future research should focus on in order to fill the existing gaps in the social and economic picture of this business and allow business developers to make sound choices.

The main reference for this chapter was the manual entitled "Managing the Double Bottom Line: A Business Planning Guide for Social Enterprises", written by Sutia Kim Alter, 1999 and published by the non-profit organization Save the Children Federation.

5.1 The business scenario

In Nepal, most people, both in urban and rural areas, are exposed to the risk of drinking unsafe water. Bacteriological contamination is present at the source or occurs in the distribution system or originates from improper handling and storage.

People are generally aware of the negative effects on health caused by the use of microbiologically contaminated water and middle-class Nepali households in urban areas often

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[7] For the meaning of "social business", I followed the definition suggested in Alter S. K. (1999), that social enterprises operate with the double goal of being financially self-sufficient meanwhile creating economic opportunities for the poor.

practice disinfection procedures, such as boiling and filtering with a candle filter system. The extent the disinfection procedure is practiced depends on various factors, including education, income, and season of the year.

While boiling is generally applied properly and produces effective disinfection, the reliability of filtration with a candle filter system is often questionable (Sagara, 2000), both because of the intrinsic inefficacy of the candle filter used or because of re-contamination of water in the storage receptacle. Therefore, the combined boiling and filtering treatment is commonly considered the best disinfection practice by middle class urban residents. Table 5.1 lists the main characteristic of the traditional disinfection methods.

Table 5.1 – Characteristics of boiling and filtering as disinfection procedures

Characteristic	***Boiling***	***Filtering***
Effectiveness against microbial contamination	100% for all forms of pathogens if sufficient time is provided (at least 10 minutes) (CDC, 2002e).	Questionable for viruses and bacteria. More effective for cysts, spores, and worm eggs.
Initial investment	None (stove and containers for boiling are usually part of the kitchen equipment)	Varies between NRs 300 (US$ 4) for a Nepali terracotta single candle filter, to NRs 1500 (US$ 20) for an Indian metal case double candle filter (Sagara, 2000).
Operational cost	High, if kerosene is used (12-17 NRs/L) Low, but time consuming, if firewood is used	Medium – annual replacement of the filter candle at NRs 35 each (US$ 0.5) (Sagara, 2000).
Process time	20-40 minutes for 5 liters (10 – 30 minutes for heating + 10 minutes of boiling time) + time for getting the fuel (firewood)	Depends on flow rate and may vary between 1.5 and 10 hours for 5 liters (flow rate between 0.5 and 3 L/h) (Sagara, 2000).
Water temperature	High (requires additional time for cooling)	Usually low (because of the thermal insulation provided by the ceramic container)
Water taste	Uneffected	Usually uneffected
Quantity of water treatable per cycle	Limited (3-5 liters)	Medium (10-20 liters)
Risks in the process	Burns	None
Production of waste	Ash + emissions of exhausted gas	Used up candle filter

As evident from Table 5.1, the combination of boiling and filtering can be very expensive and time consuming. Therefore, most of the middle class and poor people who cannot afford more than one filter and have limited budgets for buying fuel, do not usually treat the entire amount of water they use daily.

The introduction of a cheaper and quicker disinfection product would allow households to disinfect larger amounts of water. Moreover, the introduction of extensive water chlorination has been a major factor in improving health in the developed countries (AWWA, 1999). Similarly, it has been shown to contribute significantly in improving health in developing countries (CDC, 2002f)[8]. Therefore, it is expected to have the same beneficial effect in situations such as those encountered in Nepal where centralized water treatment and disinfection are inadequate, where sufficient residual chlorine is not maintained in the distribution system (Shrestha, 2001), or where chlorine or any other form of disinfection is entirely lacking.

5.2 The business idea

Disinfection with a (sodium or calcium) hypochlorite solution is a water treatment technology alternative to boiling and filtering. The microbial contamination is not eliminated through a physical mechanism, such as heat, as in the case of boiling, or mechanical entrapment, as in the case of filtering, but via chemical reactions – mainly direct oxidation of the microbial cells. The consequences of this different disinfection mechanism are evident by comparing Table 5.2 against Table 5.1.

Table 5.2 – Characteristics of hypochlorite disinfectants

Characteristic	***(Sodium or Calcium) Hypochlorite Disinfectant***
Effectiveness against microbial contamination	High against viruses and bacteria Almost none against spores and cysts
Investment cost	None
Operational cost	Low

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[8] An example of successful chlorine disinfection program for developing countries is the Safe Water System, created by the Centers for Diseases Control and Prevention of the U.S. Department of Health and Human Services and implemented in various developing countries (Zambia, Bolivia, Madagascar, Pakistan) in the recent years. Some implementation cases of CDC's Safe Water System, and a similar program implemented in Nepal, are reviewed in Sullivan (2002).

Process time	30 min. (independent of the volume)
Water temperature	Unaffected
Water taste	Slight to moderate depending on chlorine residual
Quantity of water treatable per cycle	Unlimited
Safety risk	Yes, if product is used improperly
Production of waste	Plastic bottle (if return/refill option is not available)

Compared to boiling, hypochlorite disinfectants have the advantage that they complete disinfection in a time (30 minutes) that is totally independent of the treated volume of water (given a sufficient dose and proper initial mixing). This fact encourages the disinfection of larger water volumes. On the other hand, with respect to filtration, hypochlorite disinfectants have the advantage that they can be dosed directly into the containers used to collect and store water, without any initial investment for a specific filtration device (assuming a low source water turbidity). Therefore, hypochlorite disinfection is a solution immediately available to households of almost any income level. In addition, chlorine disinfection has proven more reliable than existing household candle filters in terms of effectiveness against viruses and bacteria[9].

Because of these advantages of hypochlorite disinfection, in 1998 ENPHO started to produce a calcium hypochlorite solution, called Piyush, using the process described in Section 3.3. The product was specifically intended to substitute for boiling and provide a cheap disinfection system that a large share of the population could afford and adopt. Wide adoption would have three main positive effects: increase people's health since a larger quantity of water would have been treated, reduce the consumption of fuel and thus the impact on the environment, and make money available for alternative uses. Figure 5.1 shows a scheme of the expected effects of introducing hypochlorite disinfection.

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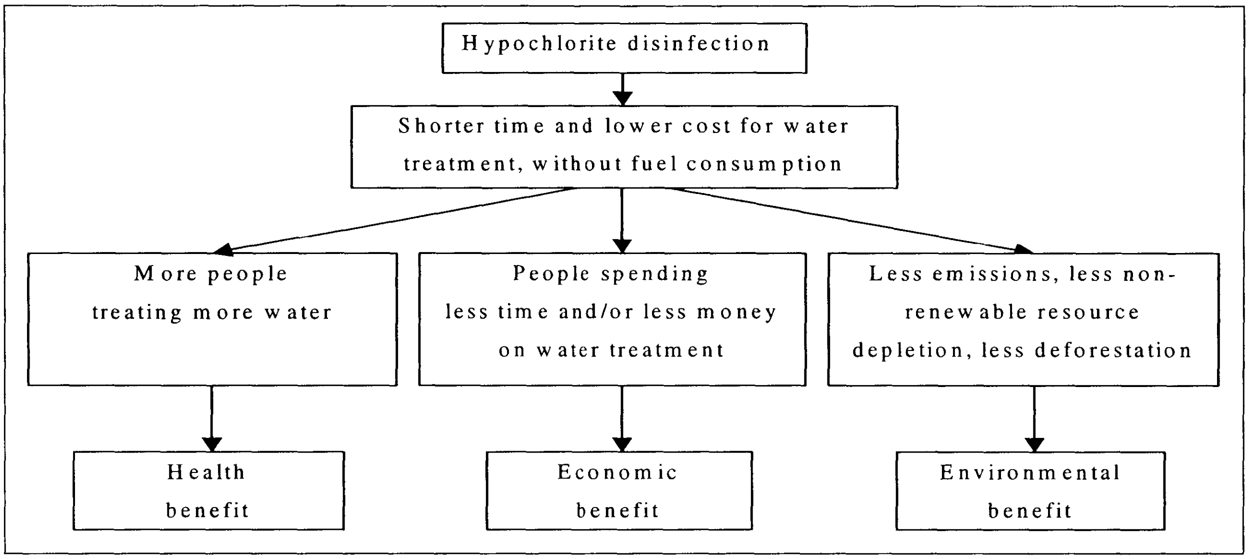
[9] Ongoing research by the MIT Clean Water for 1.7 Billion People Projects (Nepal, Haiti, Nicaragua) focuses on technologies such as biosand filters and teracotta filters both with sufficient flowrate and high efficiency in removing bacteriological contamination. Since the operational cost of the filters is virtually zero, this would represent an optimal solution, given that the manufaturing cost is low enough to allow wide adoption of such filters. Meanwhile, chlorination is an important addition to filtration, to ensure effective virus and bacteria removal, but cannot replace filtration completly, since its action is insufficient against cysts and spores. The combination of filtration and hypochlorite disinfection is a good mid-term solution for those areas where cyst-caused diseases are reported. For more information, refer to Low (2002) and Luckacs (2002). Moreover, chlorine disinfection is essential to clean water storage vessels.

Since the installation of the SANILEC-6 hypochlorite generator in January 2002, ENPHO is in a better position to provide continuous production of hypochlorite solution, without depending on the importation of bleaching powder from India, and can now implement a strategy to create a hypochlorite business in Nepal.

Figure 5.1 – Effects of replacing boiling with hypochlorite disinfection



5.3 The target market

5.3.1 Market segments[10]

Safe water is a basic need; therefore, the market for products such as Piyush includes virtually everybody who still lacks a safe water supply (33% of the 23 million Nepalese population, according to a World Bank document (2001a); however, this datum seems over-optimistic when compared with Shrestha (2001b), and the actual conditions experienced in January 2002). This large pool of customers, however, is not accustomed to disinfecting water with a chemical product and, therefore, specific strategies are needed to introduce the product

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[10] With this term, different sub-groups of customers are indicated within the same market, in order to distinguish between specific needs and preferences that are relevant in order to provide a better product or service.

into Nepali society, where education, mass media penetration and financial resources are often limited.

In addition to customers who would directly benefit from safer drinking water, other sectors may be interested in buying a water disinfection product such as Piyush, with the purpose of re-selling it or using it in their business. Formal and informal retailers of health care or household products, both in the urban and rural areas, could include the disinfectant in their merchandise; food and drink street vendors might be interested in using it to provide their clients higher quality and additional value to their goods; restaurants and hotels may use it to disinfect the water supplied to clients or used for food preparation. NGOs could be interested in buying Piyush in bulk quantities for implementing disinfection programs in rural areas. Lastly, public entities such as schools, hospitals and water treatment plants would potentially buy the product to provide safe water to the portion of population they serve (students, patients, citizens). Table 5.3 lists the main customers segments and their principal interests.

Table 5.3 – Market segments for Piyush and their characteristics

Market Segments	***Characteristics***
Low & medium income households in urban areas	Occasionally boil or filter small amounts of water. Might need hygiene education.
High-income households in urban areas	Are used to boiling and filtering. Have more resources to allocate for health care and prevention.
Households in rural areas	Occasionally boil and filter small amounts of water. Might need hygiene education.
Formal retailers (in Kathmandu and other major towns)	Are interested in promoting and selling Piyush if there is a mark-up.
Informal retailers (in the rural areas)	Are interested in promoting and selling Piyush if there is a mark-up. If village-based educational groups (such as women motivators) are involved, a synergy with educational programs can be established.
Street water and food vendors	Might be interested in disinfection if this gives a competitive advantage to their products.
Restaurants and hotels	Are interested in providing safe water and food to their clients.
NGOs carrying out disinfection programs	Are interested in constant, reliable and cheap supply.
Schools	Are interested also in water monitoring service.
Hospitals	Are interested also in water monitoring service.
Public water treatment plants	Are interested in the product if sufficient supply can be constantly provided and it is easy to use.

Specific strategies must be tailored for each market segment. Some basic suggestions to do this are provided in the Section 5.4. Before that, however, is important to identify the existing alternatives currently available for household water disinfection, and possibly design a model to interpret the behavior of customers, when they face the choice between alternative disinfection solutions.

5.3.2 Alternatives to Piyush

Up to the present (May 2002), ENPHO is the only Nepalese manufacturer of a hypochlorite drinking water disinfectant. Chlorine and iodine tablets for water disinfection that might be found in Kathmandu in selected retails store have the same function as Piyush, but they are imported products and, therefore, have a price that is affordable only to very healthy Nepalis or more typically to foreign customers.

Bleaching powder, which could be used for water disinfection, is imported from India by a Nepalese wholesaler, which supplies the water treatment plants of Kathmandu. The powder is not available in the retail shops, and anyway its direct use for water disinfection would be hindered by the consistent residual of lime produced, which results in unpleasant turbidity of the treated water, as experienced by ENPHO in the manufacturing process of the former Piyush. In addition, the supply from India is discontinuous and unreliable.

Harpic™ (Reckitt Benckise) and Brisk™ (Henkel) are similar to Piyush in the sense that they are disinfectant solutions containing hypochlorite, but their use is strictly limited to house-cleaning, since hypochlorite is mixed with fragrances and deodorants that are not suitable for water disinfection. These products are readily available in retail shops in Kathmandu, but since they are imported from India, they have a price (NRs 65 per 0.6 liter bottle) affordable only to high-income households, which is the market segment they target.

Even if Piyush is now the only product in its category, it has to compete with the other traditional disinfection systems. The next section discusses in detail the competitive advantage of chlorine over two other traditional disinfection systems, boiling and filtering with candle filters.

5.3.3 Competitive advantage of Piyush and customer's behavior model

In order to identify the most appropriate strategy for a market segment, it is useful to have a conceptual scheme of the approach used by the customers in that segment to make their choice between alternative disinfection methods. In this section, a simple model of the behavior of urban households is proposed.

The model assumes that the choice between disinfection methods is based on the time and the money needed to carry out the disinfection process. Figure 5.2 and Figure 5.3 are the output of the model[11] and show the amount of money and time spent to treat a given amount of water depending on the process adopted. For each process, the following data were assumed:

Boiling	***Candle Filtration***	***Chlorination (Piyush)***
Volume boiled per cycle: 5 L	1 filter with 2 ceramic candles	Hypochlorite disinfectant
Cycle duration: 30 min (total boiling time calculated according to the number of cycles in a day)	Flow rate: 3 L/h (total filtration time calculated according to the water quantity)	Reaction time for hypochlorite (independent of volume): 30 min.
Fuel (kerosene) consumption: 0.12 L/h	Product life: Filter: 2 years Candle: 1 year	Hypochlorite concentration: 5000 mg/L
Fuel cost: 10 NRs/L (cost calculated according to the number of cycles and fuel consumption)	Costs: Filter: NRs 300 Candle: NRs 35 ⇒ Total yearly cost: NRs 220 ⇒ Daily equiv. cost: NRs 0.60	Chlorine dosage: 0.75 mg/L Cost of a bottle: NRs 17 Disinfect bottle size: 60 mL (cost calculated according to the quantity to disinfect)

Figure 5.2 clearly shows that for daily water consumptions above 15 L/day, filtration with a candle filter is the solution with the lower daily cost. This is due to the fact that the cost is not proportional to the amount of water treated. However, many households might not afford the initial investment required for buying a candle filter, and therefore they may boil some minimum volume of water used for drinking (below 10 liters/day per household). As soon as people can afford a candle filter, they are likely to switch to this solution but then they are limited by the time required to carry out filtration (Figure 5.3).

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[11] The model for comparing different disinfection systems is implemented in the EXCEL spreadsheet "Consumer cost", in the PIYUSH.XLS file on the companion floppy disk. A particular scenario is also reproduced in Appendix I.

The X and Y axes in Figure 5.2 and Figure 5.3 can be reversed to obtain Figure 5.4 and Figure 5.5 respectively. These Figures can be used to determine the quantity of water a household would treat, given the amount of time and money available for disinfection.

Figure 5.2 – Money spent for disinfection depending on treated volume

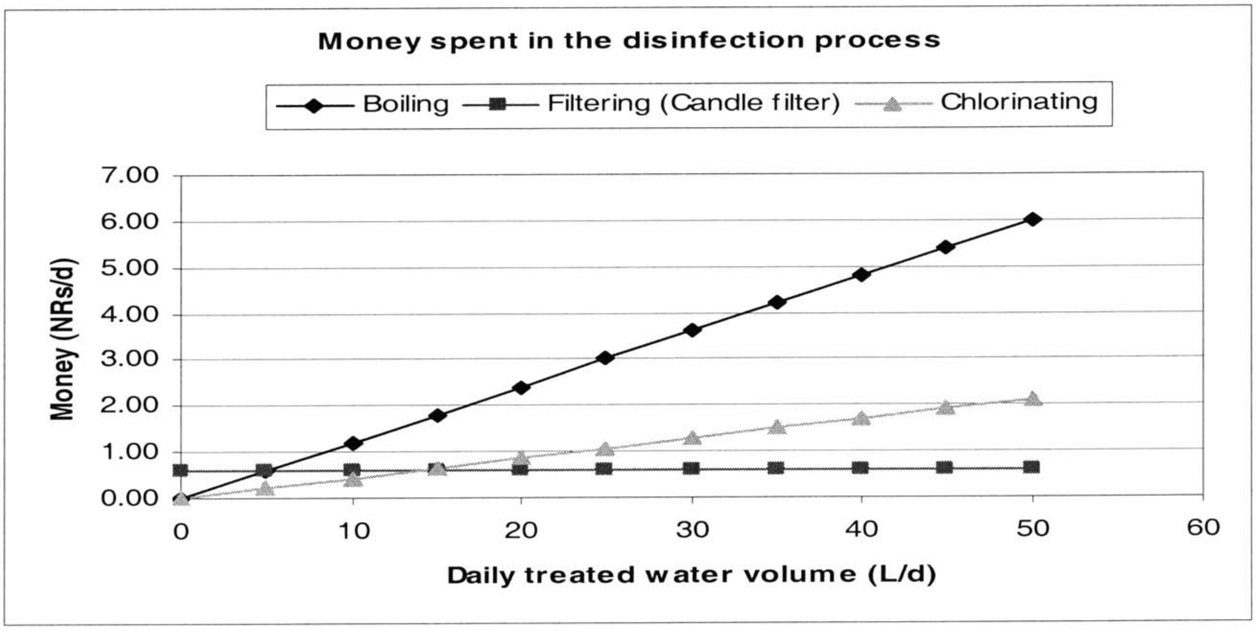


Figure 5.3 – Time required for disinfection depending on treated volume

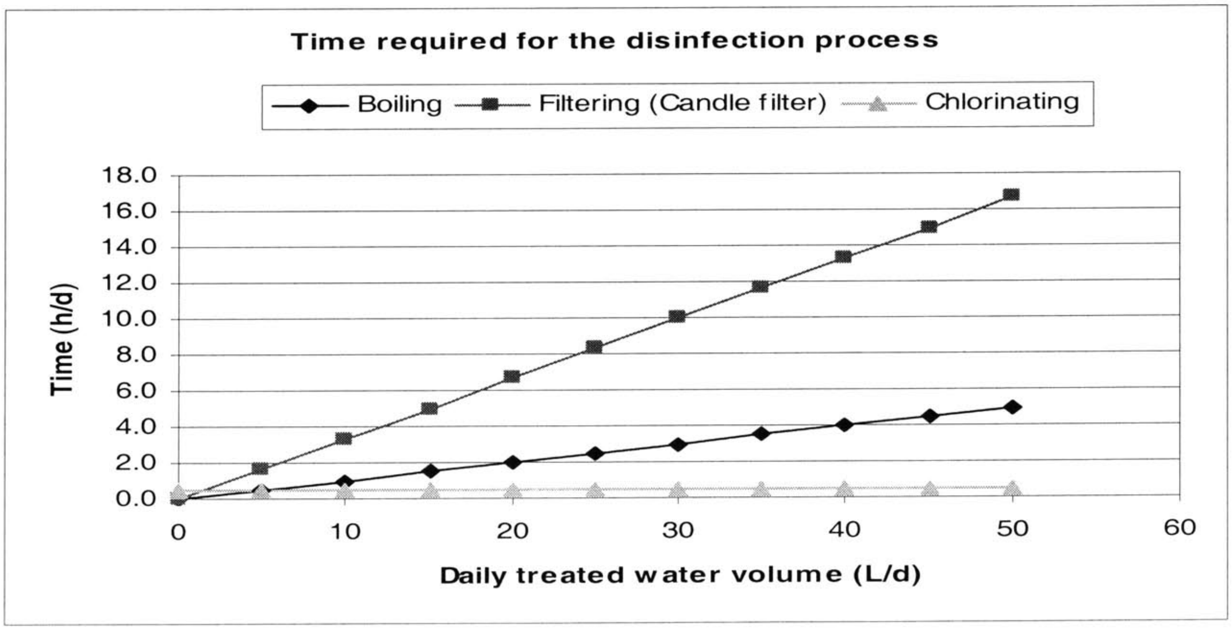


Figure 5.4 – Treatable water volume vs. money allocated for disinfection

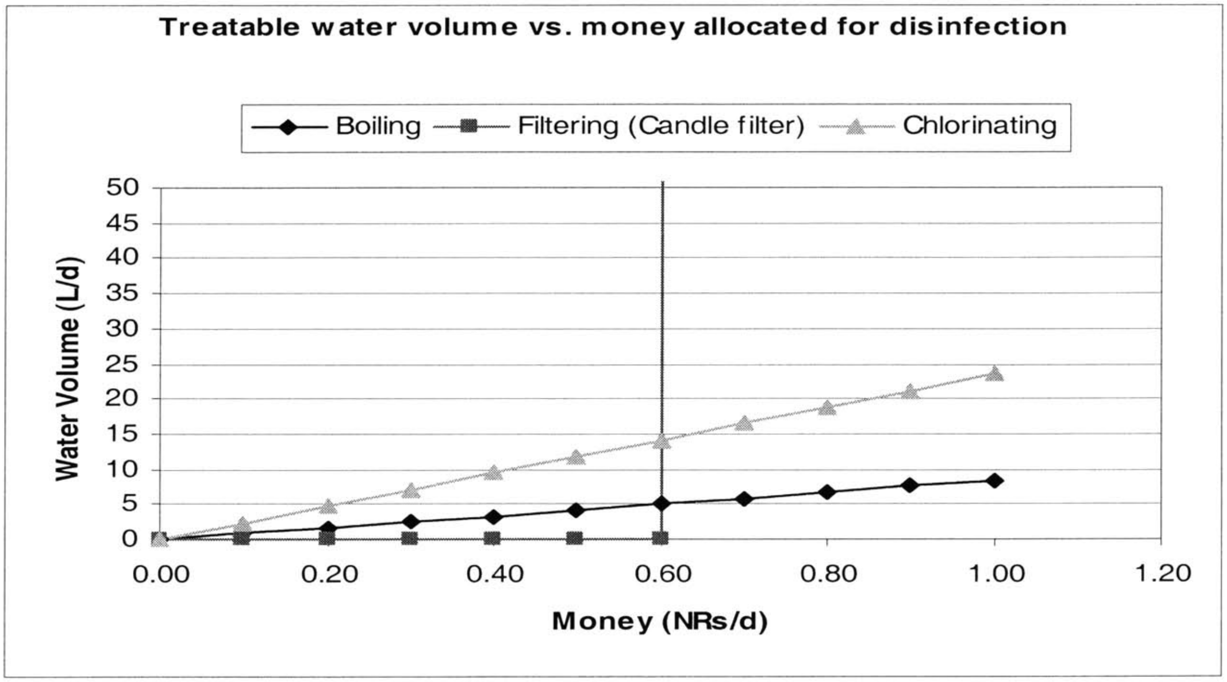
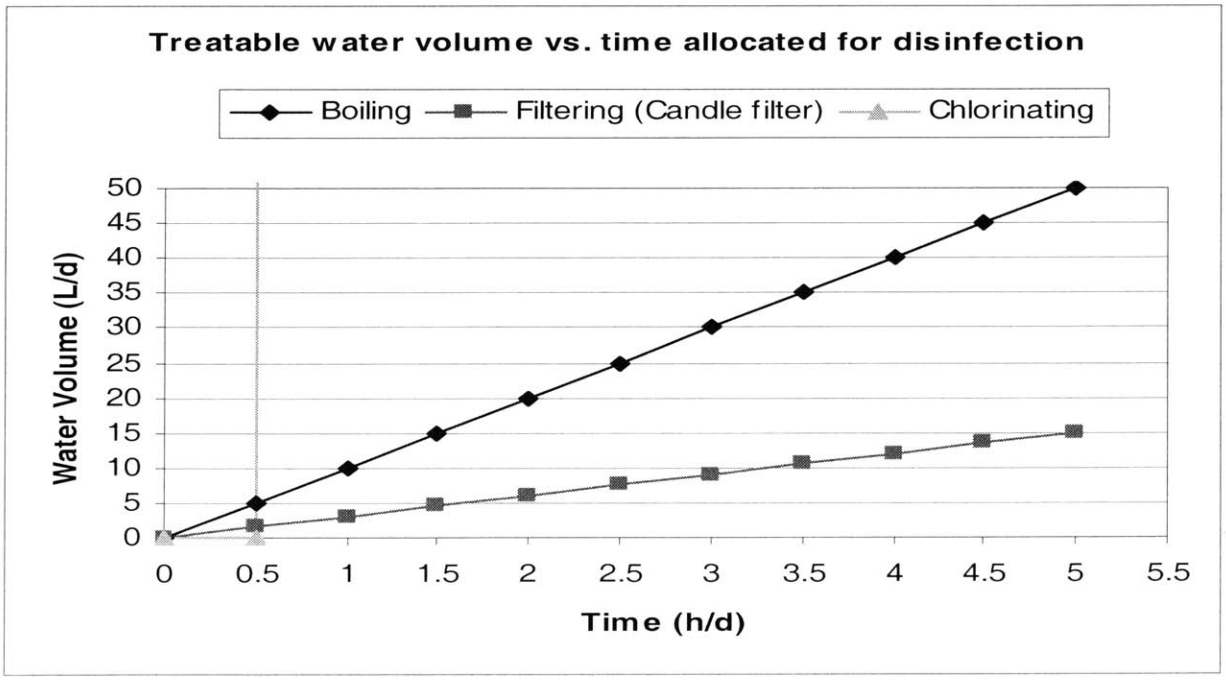


Figure 5.5 – Treatable water volume vs. time allocated for disinfection



These graphs allow us to evaluate the benefit in terms of increased volume of treated water that derives from the introduction of hypochlorite disinfection. First, let's consider the case of a low-income family that cannot afford the initial investment in a candle filter. This means that the daily capability or willingness-to-pay for water disinfection is below the threshold of NRs 0.60 per day (from Figure 5.4), which is the equivalent daily cost for a candle filter. Therefore they would boil their water, but because of the budget constraint they boil only a very small amount. Assuming NRs 0.50 per day are allocated for disinfection, the daily treated water is about 4 liters. In fact, many poor families do not practice disinfection at all and might use boiling only occasionally, typically for very young children or the very old. If hypochlorite was available, Figure 5.4 shows that the treatable amount of water at the same total cost is 12 liters per day (increase of 200%).

In the case of a richer household that can afford a filter (money allocated for disinfection is above NRs 0.6 per day), the limit on the quantity of treated water is given by the waiting time. Figure 5.5 shows that, for example, the family would probably have to wait 5 hours to get 15 liters when filtering with a candle filter. With the adoption of household chlorination with hypochlorite, the same water quantity would be available in 0.5 hour. However, the cost for this quantity is higher than 0.60 NR/s. Therefore, the household will take advantage of the reduced time to increase the quantity of water to the point at which the benefit of a larger quantity equals the increased cost of the disinfection treatment. The perception of this benefit is largely dependent on the awareness of the family of the safer condition resulting from chlorination, and this explains the importance of coupling Piyush promotion with health education programs. If people with a filter do not perceive that hypochlorite disinfection is safer than filtration (at least for viruses and bacteria), they will not switch from filtration to chlorination.

In addition, hypochlorite promotion might be hindered by the fact that improper excess dosage produces unpleasant taste, which might keep people from using it. Instruction and education on proper dosage would avoid this problem and minimize customer dissatisfaction. As discussed in Section 6.3, the educational component is essential in promoting hypochlorite disinfection, since it targets the two-fold purpose of overcoming the cultural barrier against the new product and creating the mental link that chlorine taste is an indicator of safe drinking conditions.

5.4 Marketing plan

Once the specific needs of each customer segment have been clearly identified, the next step is to develop the appropriate mix of products and services that meet those needs at a price that customers are willing to pay. The marketing plan considers the best strategy for selling the product/service and, to that end, relies on four fundamental components: evaluation of strengths and weaknesses the product, definition of a price that meets customer's willingness-to-pay, design of an effective marketing campaign and identification of distribution channels. These elements are strictly interconnected, since, for example, a particular form of distribution may be related to a specific marketing technique, which also effects the price, etc.

In this section the characteristics of the existing Piyush are reviewed and then guidelines for its pricing, promotion and distribution are provided, based on the needs of the different market segments.

5.4.1 The product

ENPHO has been manufacturing Piyush, in the form of calcium hypochlorite disinfectant, since September 1998, using the process described in Section 3.3. During the last four years, ENPHO has improved the quality and the look of Piyush, which nowadays shows characteristics aligned with the standards of reliability and functionality of formal products sold elsewhere in the global market.

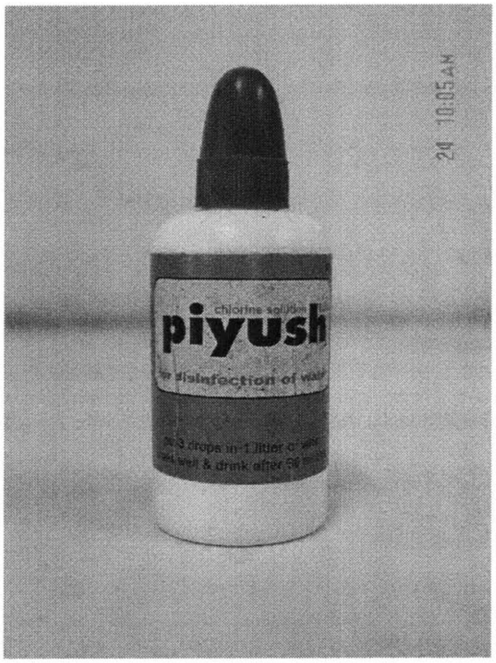
Since January 2002, ENPHO has the option of using the new production process described in Section 4.3, which replaces a calcium hypochlorite product with sodium hypochlorite product. Even though there is a new production process, ENPHO is not planning to change the name and the look of the product, whose function and efficacy are the same as in the previous formulation. Therefore, in the next sections, no distinction between the former and new Piyush will be made.

Piyush is currently packaged in 60-mL white plastic bottles with a blue label (Figure 5.6). The label displays the following information:

a) Name of the product (Piyush)

b) Nature of the product (chlorine solution 0.5%);

Figure 5.6 – Piyush 60-ml bottle



c) Purpose of the product (water disinfection);

d) Dosage and use instruction (3 drops per liter / shake well and drink after 30 minutes);

e) Nominal volume of the solution contained (60 mL);

f) Price (17 Rs);

g) Producer name and its address (ENPHO, New Baneshwor, Kathmandu);

h) Date of manufacturing;

i) Batch number;

j) Validity of the product (one year from the manufacturing date);

k) Storage requirements (store in a cool and dark place).

Elements a), b), c), and d) are written in Nepali, in addition to English.

The latest version of the label, which was available at the ENPHO lab but was not found on the bottles sold in the shops yet as of January 2002, had additional information about the wholesaler (Minko Pharma, Chhetrapati, Kathmandu).

The author undertook an analysis of the characteristics that might be relevant from the customer perspective for a product such as Piyush (Table 5.4), in order to identify possible improvements for its marketing. Table 5.5 is the evaluation sheet for Piyush, according to the identified characteristics.

Table 5.4 – Product characteristics

Objective	***Specification***	***Method to achieve the objective or tools to support the product***
Reliable	In the quantity	Quantity control (weighing of the bottles)
	In the concentration	Quality control (random tests for available chlorine)
	In the effect	Literature on chlorine disinfection Epidemiological studies
Easy	To find/purchase	Wide distribution network
	To understand	Clear instructions with common words

	To use	The package includes everything required and the product is almost immediately effective
	To manage	Storage requirements are easy to accomplish and packaging is optimized for the typical use rate
Safe	The product is not a threat to health	Absence of toxic components, dangerous parts, etc. and clear use and storage instructions
Versatile	The product can be used for different applications	Integration of different uses in a single product
Affordable		Optimized production process
Appealing		Appropriate packaging and advertising

Table 5.5 – Piyush evaluation sheet

Objective	***Specification***	***Piyush score***	***Rationale***
Reliable	In the quantity	YES	The variability is below 10%
	In the concentration	YES	The variability is below 10%
	In the effect	YES	Hypochlorite effectiveness is proven
Easy	To find/purchase	?	Depends on the distribution plan
	To understand	YES	The label is simple and written both in English and Nepali
	To use	Not always	Easier dosing method can be suggested in case of large water volumes (ex. use of the cap instead of counting drops. See Section 4.5.7).
	To manage	YES	The bottle is enough to disinfect 400 L (about 10-15 days at 24-40 L/d per household)
Safe	The product is not a threat to health	YES	Hypochlorite concentration is low
Versatile	The product can be used for different applications	NO	The product can be used only for water disinfection. The chlorine concentration is too low for effective house-cleaning or bleaching
Affordable		?	A real willingness-to-pay survey has not been carried out but would be one basis for evaluation
Appealing		YES	The bottle is aesthetically nice

Applying the evaluation criteria of Table 5.5, Piyush seems to meet the main requirements of being attractive to the household segment in Kathmandu, which demands a reliable, safe and easy-to-use product.

For the other market segments, different packaging might be more appropriate. In fact the 60-mL bottle is sufficient for the water consumption of a household for 10-15 days, if the treated water has a chlorine demand around 0.5 mg/L.

In rural areas, especially in monsoon season, the chlorine demand of water drawn from surface sources such as ponds, rivers and open wells, might be as high as 1 – 2 mg/L or even higher, and therefore the suggested dose might be not enough to provide sufficient free residual chlorine. If the Piyush dose is increased, then the consumption also increases and the volume of a single bottle may be too small. For example, if a dose of 1.5 mg/L is required, a single 60-mL bottle would be enough for 175 liters, which means a duration of about a week for a household treating 25 liters per day[12]. In addition, the schedule of distribution should be considered: remote rural areas might be difficult to reach, and lower frequency of purchase is preferable for these communities. In general, the packaging should be corrected considering the real chlorine demand of the water to be treated and the ease of distribution of the product in the target area.

A totally different marketing approach is required for NGOs, schools, hospitals and small public water treatment plants, the last four categories in Table 5.3. These customers are particularly important because they are likely to need large amounts of bulk disinfectant solution, on a regular basis, and are easy to identify and reach on the market place. In addition, schools and hospitals do not usually have internal expertise in water treatment, thus outsourcing of water disinfection services is the solution they might prefer. ENPHO should aim to establish a regular collaboration agreement with these customers, embedding the supply of the disinfectant in a more comprehensive water monitoring service (water analysis and residual free chlorine adjustment). An additional advantage of such clients is that, as they are public entities, usually they are (potentially, but, especially in developing countries, not always) reliable from the point of view of payment.

A similar strategy could be used with small water treatment plants. However, the present maximum daily production of Piyush can disinfect only up to 1,000 m^3 of water, with a chlorine demand of 0.5 mg/L. This amount of water is quite small for a public water treatment plant and

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[12] The EXCEL spreadsheet "Production Plan" in the file PIYUSH.XLS included in the companion floppy disk allows the user to estimate the quantity of water that can be treated with a given amount of Piyush, once the target FRC and the water chlorine demand are input. The spreadsheet is reproduced in Appendix H.

therefore such clients should be considered only if higher daily hypochlorite production is possible.

5.4.2 The pricing strategy

Different forms of Piyush (bulk solution or bottled) may have different prices that reflect the different production and distribution costs, the accompanying service provided with the product and the willingness/capability to pay of the targeted customer segment. The production costs analysis in Section 5.5.2 shows that the bulk sodium hypochlorite solution is much cheaper than the same solution packaged in 60-mL bottles (the content of a 60-mL bottle accounts for less then 5% of the net production cost). This means that the pricing may change consistently depending on which packaging is used to deliver the product (for example, the price for the bulk solution has to be set on the basis of a pure production cost of NRs 5.00 per liter, while for the 60-mL bottle, a production cost of NRs 6.25 per bottles applies).

Another important element to evaluate in defining a price for Piyush is the customer's willingness to pay for it. A market survey with this purpose has not been carried out yet, but would be extremely useful to estimate the expected amount of revenues of the business. In rural areas, customer's willingness-to-pay might be difficult to estimate, since the economic value of health is not clearly defined (people do not have direct access to medicines and medical services are often either unavailable or are provided for free) and alternative disinfection methods with which to compare household chlorination are uncommon or non-existent. In addition, in villages where Piyush has been distributed as part of a subsidized chlorine disinfection pilot program (for example, in Lumbini), the households' willingness to pay might be distorted by the expectation that the product continues to be given free.

The subject of subsidies is an important one to address in relation to the issue of financial sustainability of Piyush micro-enterprise. It might be an explicit goal of the enterprise to subsidize Piyush in order to reach a larger share of the market. However, this will make the micro-enterprise dependent on the availability of financial support from donors or other sources, and can undermine its sustainability in the long term. A subsidized price might be used only for special customers with whom ENPHO is willing to collaborate on social programs. For example, ENPHO could agree on a special price or even "at cost" supply to NGOs carrying out disinfection programs.

5.4.3 The promotion and distribution strategy

The household segment, although the most significant numerically, cannot be reached directly, especially outside Kathmandu. Retailers and informal distribution centers in the rural areas represent the necessary intermediate distribution level.

Since Piyush is almost a completely new product, the main goals for ENPHO's promotion and distribution campaign are:

- Introduce Piyush in the community which have no knowledge of chlorine water disinfection;
- Increase awareness about the role of safe water in providing improved health and make explicit that chlorine disinfection is effective of in producing safe water, so that people willingness to pay for Piyush is augmented;
- Create a stable and trustworthy relationship with customers, so that they think at Piyush as an indispensable element of their daily life.

This last point is essential to guarantee constant demand during the year and stable health improvements. Other experiences in this field show (CDC, 2002b) show that household customers tend to be inconstant in purchasing disinfectants, due to variable budget and changing perception of disinfection need during the year (in the periods of water scarcity and during the rain season, when water quality declines, sales are higher than during the rest of the year).

It is unlikely that ENPHO has sufficient human resources for directly promoting and distributing Piyush in the rural areas. For this purpose, collaboration can be established with local groups that are constantly present in the field and are already involved in educational programs. For example, if groups of women motivators are active in teaching childcare, hygiene and nutrition, they can be provided with Piyush bottles to be sold in the villages and an agreement can be established for sharing the profit from the sales. This strategy would have the two-fold benefit of improving health and distributing the economic benefit of the business in rural areas. A scheme of the distribution system is given in Figure 5.7, and economic evaluations are summarized in Table 5.6. Adopting a fair price structure, it would be possible for the central producer to recover production costs, make some profit (if this is a goal of the social business enterprise) and make Piyush distribution profitable for local people.

Figure 5.7 – Piyush distribution strategy for rural areas

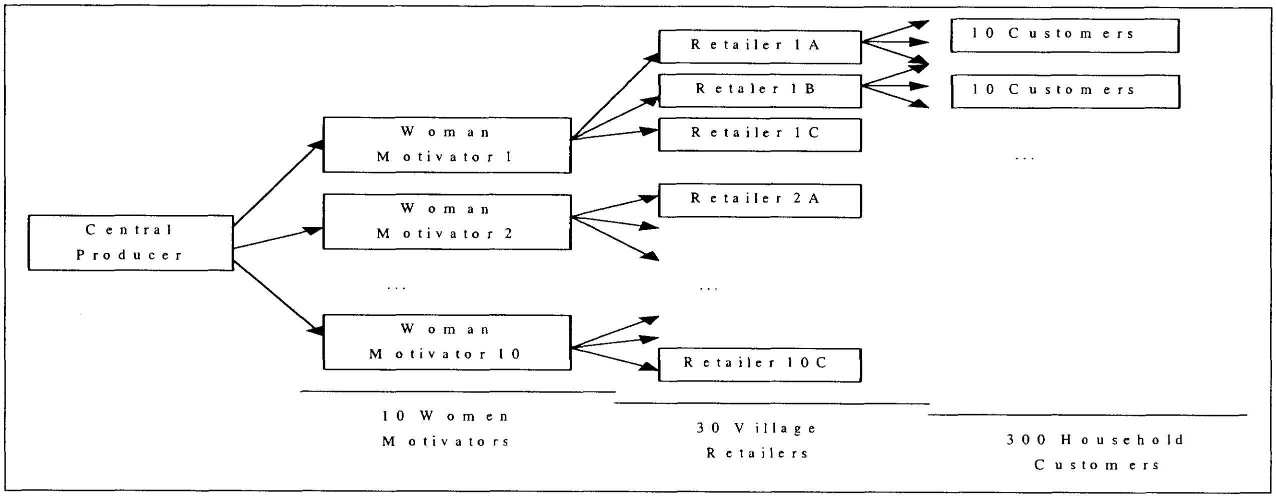

Table 5.6 – Example of economic scheme for rural distribution of Piyush

Structure of the distribution chain (numbers refer to a monthly cycle)					
Total # of bottles sold by CP	600	Village Retailers (VR) per WM	3	Customers per VR	10
Women motivators (WM)	10	Total # of VR	30	Total # of customers	300
Bottles sold to each WM by CP	60	Bottles sold to each VR	20	Bottles sold per customer	2

Balance for each category	***For Central Producer***	***For Women Motivator***	***For Village Retailers***	***For Customers***	***Total***
Buying Cost	10*	12	14	17	
Selling Price	12	14	17	-	
Revenue	7200	840	340	-	10200
Expense	6000	720	280	34	6000
Profit	1200	120	60	-	4200
Margin (P/R)	17%	14%	18%	-	41%

* For the Central Producer, the buying cost is actually the production cost.

Distribution of profit			
Total profit for the category	1200	1200	1800
Percentage at each level	28.6%	28.6%	42.9%

In areas where household income is very low and the Piyush is likely to be unaffordable in the 60-mL version, a strategy based on rechargeable bottles can be adopted. In this case, a local retailer would distribute reusable bottle and would sell the bulk disinfectant solution both to people coming to the central shop or delivering the solution house by house. While carrying out the distribution, the Piyush vendor could also promote the product in the neighborhoods of the household already using the product and provide education on safe water.

Another viable distribution technique would be using existing well-organized distributors of imported products (ex. Coca Cola), which could include Piyush in their distribution system at a very low cost. For example, in tourist areas of Nepal, products for tourists are widely and efficiently distributed and the same distribution pathways might be used for Piyush.

The household segment can also be reached through children who attend schools were chlorine disinfection is explained and promoted. A survey conducted in Lumbini, where a Chlorination Pilot Project was started in January 2001 (Sullivan, 2002), revealed that children might be involved in chlorination promotion, since they are prone to talk about chlorination in their families, spreading around interest for disinfection to their parents.

5.5 Production and costs assessment

5.5.1 Production capacity

Assessing the production capacity of the SANILEC-6 generator is important in order to plan the frequency of Piyush production. With the standard cycle described in Section 4.3.3, 150 liter of 0.5% available chlorine solution can be produced every cycle (i.e. 0.75 kg of available chlorine per production day). Assuming a chlorine demand of 1.0 mg/L of available chlorine[13], the daily production is sufficient for treating 750 m^3 per day of water. The number of people potentially served depends largely on the assumed quantity of water treated by each household.

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[13] This dose may vary significantly during the year and depending on the area considered.

If each household is assumed to disinfect 25 liters per day, 40,000 households can be supplied for one day with the production of a single batch[14].

5.5.2 Production cost analysis

In January 2002 the net production cost[15] for new Piyush was determined to be about NRs 5.4 per 60-ml bottle. A breakdown of this cost is provided in Table 5.7, based on the unit costs and material/labor consumption encountered in January 2002 for a standard production cycle as described in Section 4.3. In parallel with the analysis of the former Piyush process (see Section 3.4), there are three main cost categories included in the production cost: capital cost, O&M costs, and bottling costs[16]. These three cost categories are discussed below in relation to the new Piyush production process.

Capital cost

In contrast to the former Piyush process, the new process involves the use of an expensive piece of equipment – the hypochlorite generator – that requires taking into account a capital recovery cost (or amortization). Even though ENPHO received the generator as a donation and, therefore, the capital cost seems to be null, a pseudo-capital recovery cost should be included in the production cost in order to progressively accumulate sufficient funds for the eventual replacement of the generator once its life time has expired. Assuming daily use, which means an

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[14] The "Production plan" spreadsheet in the PIYUSH.XLS file on the companion floppy disk carries out these calculations. It is also reproduced in Appendix H.

[15] In this context, the "net production cost" includes all the costs the are specifically incurred for the material production of Piyush, while the "gross production cost" includes also the overhead for the production management and other ancillary services, which are available in any case, even if no Piyush is produced. For example, the salaries of the supervisor of the production process and the lab technician in charge of the quality tests, who are part of the permanent staff of the micro-enterprise, are not included in this cost analysis, but are discussed in Section 5.7.

[16] Commonly, cost analyses distinguish between fixed costs, which do not depend on the production, and variable costs, which are in someway proportional to it. Capital costs and maintenance costs would be included in the former category, while material costs, cleaning costs, and bottling costs would be in the latter. Labor would fit in one or the other categories depending on whether personnel are hired occasionally or as full-time staff. In this specific case, however, bottling cost has been considered separately to allow comparison between different bottling options. In addition, since fixed maintenance is null and labor is always provided as needed, fixed costs coincide with capital cost and variable cost coincides with the O&M cost, which includes material cost, variable maintenance and labor.

average of 250 usage days per year,[17] the lifetime of the generator is 5-8 years (White, 1999), i.e. 1,250 usage days in a conservative evaluation. Since the cost of a new unit is US$ 2000[18], an average of US$ 1.60 (NRs 120) per usage day has to be set aside in order to have sufficient funds after 5 years to replace the unit.

Table 5.7 – Break-down of production cost for new Piyush

Based on a single production cycle (2,500 bottles)		***Quantity***	***Unit Cost***	***Tot. Cost***	***Specific Cost***
		Unit/cycle	***NRs/unit***	***NRs/cycle***	***NRs/bottle***
Capital cost				**120**	**0.05**
O&M cost				**621**	**0.25**
Water	L	150.0	2	300	0.120
Salt	kg	4.5	9	41	0.016
Energy	kWh	4.6	10	46	0.018
Cleaning material (vinegar)	L	1.1	20	22	0.009
Small maintenance	-	1	12	12	0.005
Labor	day	1.0	200	200	0.080
Bottling cost				**12,838**	**5.14**
Bottling components	#	2550	4.25	10,838	4.34
Labor	day	10.0	200	2,000	0.80
NET PRODUCTION COST				**13,579**	**5.44**
NET PRODUCTION COST (in US$)				**181.00**	**0.073**

O&M costs

O&M costs include the costs for materials and labor to manufacture the sodium hypochlorite bulk solution and to maintain the unit. Maintenance cost is included in the O&M costs because, in this specific case, maintenance is proportional to the frequency of use of the generator. In contrast, O&M is here assumed to depend only on the manufacturing process and not on the particular packaging chosen for product sale, since bottling costs are evaluated separately.

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[17] This is a commonly accepted assumption, since production usually does not take place on week-ends (104 days per year), public holidays (about 7 additional days), and maintenance days (about 4 days, considering 1 hour every 7 productive days).

[18] The effect of inflation on the generator price can probably be neglected since the portion of revenues put into reserve for the generator replacement can produce an interest that compensates for inflation. This argument, however, is weakened by the fact that the unit is manufactured in the USA and would need to be bought in US dollars, while money for its replacement would be accumulated in Nepali Rupies, whose value tends to decrease with respect to US dollars.

The cost of water (NRs 2 per liter) is the actual price ENPHO pays to the private water supplier they use when the public water supply does not work.

As far as salt is concerned, NRs 9 is the price the author paid for a 1-kg refined salt packet on the Kathmandu market in January 2002. The refined salt is considered in this analysis since it produces a better disinfectant solution than raw salt, so its use is preferred (see Section 4.3.2). Almost no variation in the manufacturing cost would result from using raw salt, which costs NRs 6 per kg. In terms of price variation between different salt retailers, no difference was observed. The possibility of buying salt in large quantities in order to get a wholesale price has not been considered because of the small amount of salt (4.5 kg) required for each production cycle.

Energy consumption was calculated using the voltage and current measurements displayed on front panel of the generator rectifier. At ENPHO, the generation process lasted 16.5 h, and voltage and current were constant at 10 V and 25 A respectively. Assuming an efficiency of the transformer/rectifier of 90%, which is a common value for such equipment (White, 1999), total energy consumption can be estimated using Equation 5.1:

$$E = (I \times V \times t) / \eta$$

Equation 5.1 – Generator energy consumption

Where:

E = energy absorbed (in kWh)

I = current (in Amperes, A)

V = voltage (in Volts, V)

t = process time (in hours, h),

η = efficiency of the transformer/rectifier.

Energy consumption is 4.6 kWh for a total production of 0.75 kg of chlorine, thus the specific energy consumption is 6.1 kWh per kg of available chlorine, the same order of magnitude as that indicated by the manufacturer, i.e. 5.5 kWh/kg of available chlorine (Exceltec, 2002 b). If we assumed a higher efficiency of the rectifier, then the specific energy consumption would be closer to the theoretical value indicated by the manufacturer, but a conservative assumption was preferred. Since the energy consumption for the generator is not metered separately from ENPHO's other uses, confirmation based on the energy bill is not possible. The price for energy (NRs 10 per kWh) is an average of the current tariffs for ENPHO's consumption level.

Every seven usage days a cleaning procedure has to be performed. Its cost includes the vinegar for the cleaning bath (8 liters per time), distributed over seven productive days, i.e. 1.1 liter per cycle has to be considered. The cost of vinegar was NRs 20per liter in January 2002.

Small occasional repairs are needed for the substitution of spare electrical parts. A reasonable annual estimate of this cost is 2% of the initial value, i.e. US$ 40 (NRs 3000) per year, distributed over 250 productive days per year, which gives NRs 12 per productive day.

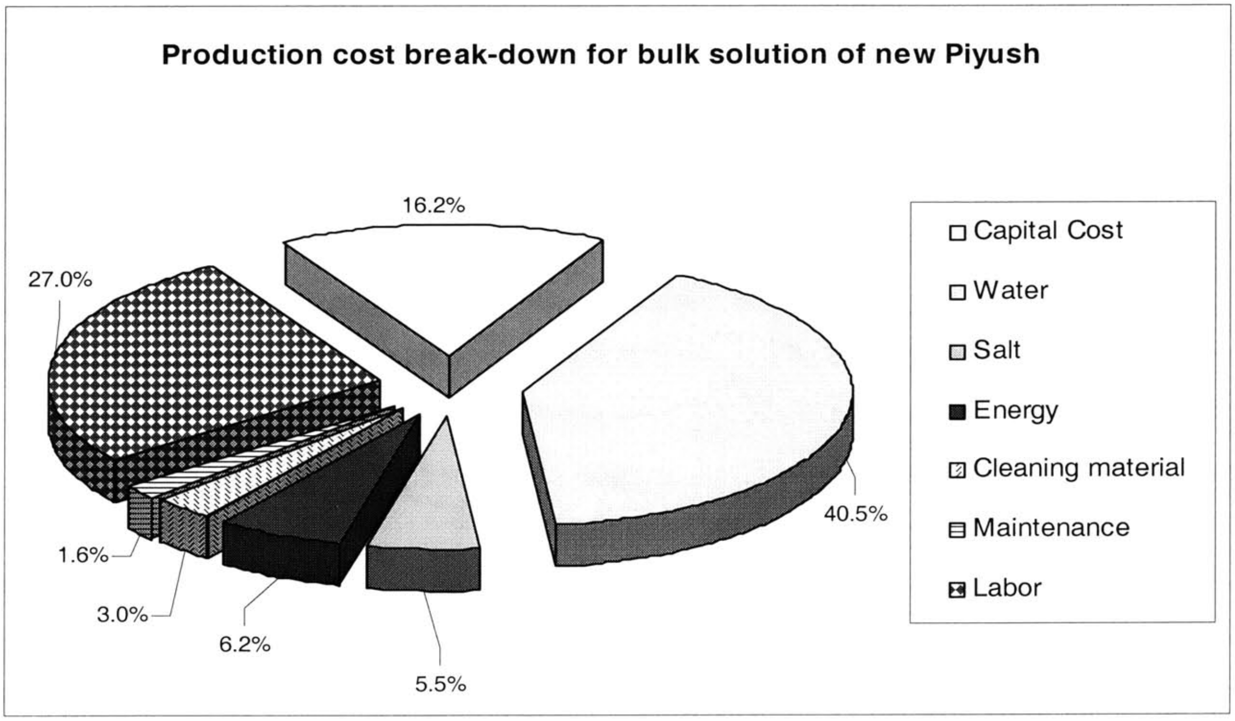
If properly planned as described in Section 4.3.1, running the production cycle will take only one day, since preparation of the brine solution can be done during the light hours and the actual reaction time occurs overnight, so that on the second morning bottling can be commenced. Running the production cycle is considered unskilled labor and is paid at NRs 200 per day. The cleaning procedure requires only a couple of hours of labor and is included in the production time.

The manufacturing cost of Piyush bulk solution (accounting for capital and O&M costs, but without packaging) is NRs 5.0 per liter. Figure 5.8 shows the relevance of each component. The three main ones are water (40%), labor (27%) and the capital amortization (16%).

Bottling cost

Bottling includes the procurement of the necessary bottling components (bottles, nozzles, caps, and labels) and the manual operation of filling the bottles, punching the nozzle (which is provided without hole), closing the cap and sticking on the label. In the evaluation of the bottling cost, the fact that a small percentage (estimated 2%) of the components purchased for this purpose do not meet the quality requirements for Piyush must be taken into account. For example, some plastic bottles were found to have thinner walls than others, resulting in a visible permeability to light. If used, these bottles do not provide sufficient protection against sunlight, which enhances the hypochlorite solution decay, and the content will have shorter shelf-life. Caps and nozzles may also be deformed or imperfect, resulting in leakage from the bottle mouth. These defective components must be discarded, and approximately 2,550 bottling components should be purchased, on average, for 2,500 Piyush units. The cost of the discarded components, therefore, has to be distributed over the cost of the sellable bottles. Even if this increased cost might seem negligible (only 2% of NRs 4.25, i.e. NRs 0.085 per bottle), it is more than four times the cost of energy or salt. This extra-cost due to imperfect components cannot be avoided, unless a higher-quality bottle can be obtained from the component manufacturer.

Figure 5.8 – Production cost break-down for bulk solution of new Piyush



Bottling is an extremely labor-intensive activity, since it is done manually, bottle by bottle. Ten days, with eight working hours per day, is considered a good estimate for bottling 2,500 bottles: an average of one bottle every two minutes was proven feasible even for an inexperienced operator. This pace can actually be reduced if a 4-5 people team is employed, with a mass-production structure (bottling, punching, capping, and labeling carried out in sequence by different employees), but the present analysis is conservative. The unit price for unskilled labor is NRs 200 per day.

It is interesting to notice (see Figure 5.9) that bottling components account for slightly less than 80% of the total cost of a 60-mL bottle, with labor, at a far lower 16.2%, being the second major factor. These values suggest that Piyush would have a much lower unit cost if it were sold in larger volumes, with the cost of the container being distributed over a larger quantity of solution.

Figure 5.9 – Production cost break-down of for a 60-ml bottle of new Piyush

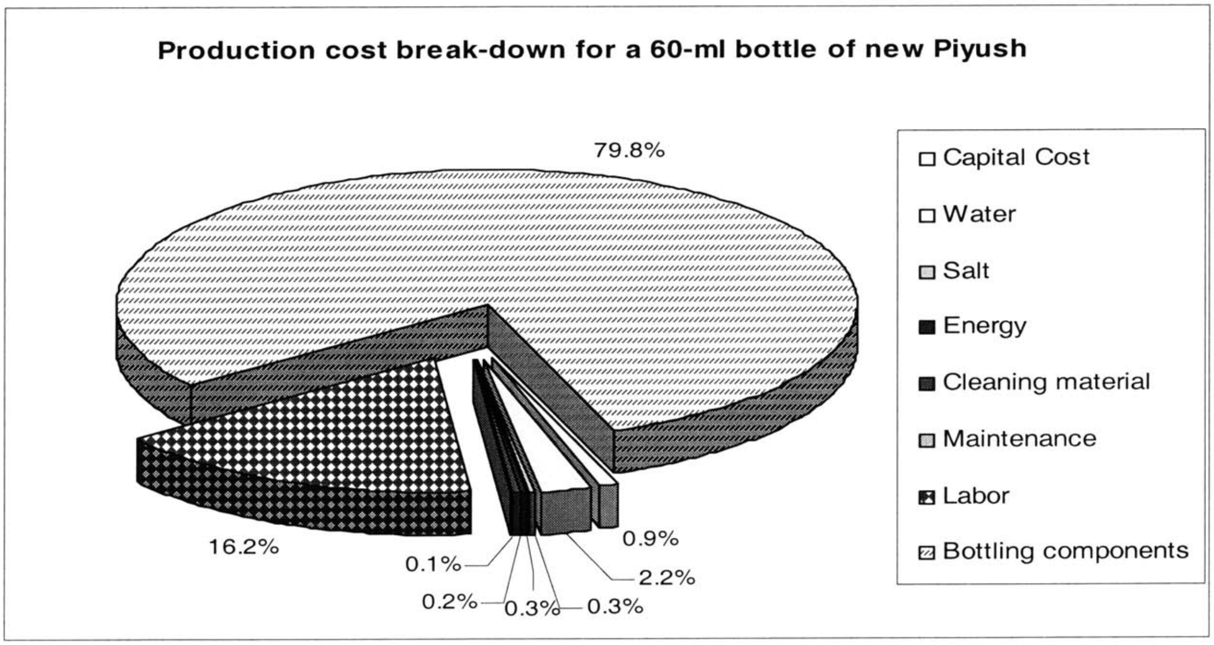
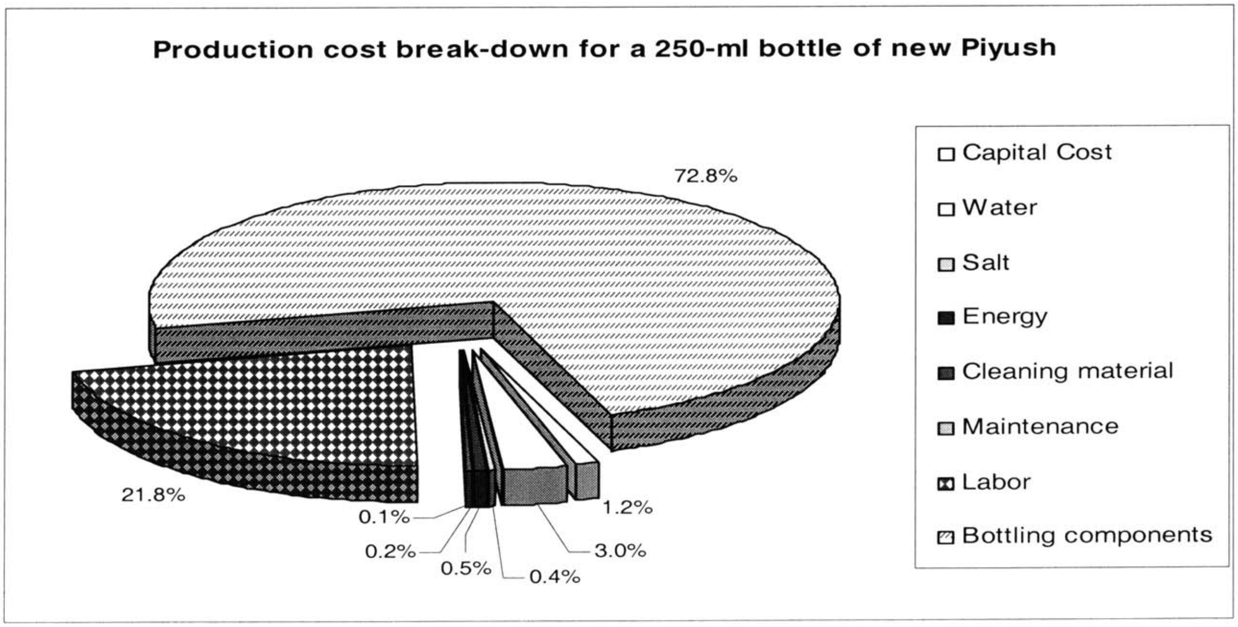


Figure 5.10 – Production costs break-down for a hypothetical 250-ml bottle of new Piyush



The cost of containers of a size other than 60 ml was not investigated in January 2002, so it is not possible to forecast precisely the cost resulting from a different packaging. However, it is likely that in Nepal, as everywhere else, the cost of plastic bottles grows less than linearly with the size (i.e. a double volume bottle costs less than double). Assuming that a 250-ml bottle costs NRs 12 (vs. NRs 4 for a 60-ml bottle) and keeping all the other factor unchanged (labor and percentage of defective bottles), the production cost for each 250-ml bottle would be about NRs 16.8, i.e. NRs 62 per liter of solution sold, versus NRs 90 per liter if the 60-ml package is adopted. Adopting a larger packaging could be a strategy to lower the unit price and reach a larger share of low-income customers.

5.5.3 Cost comparison with the former production process

The total production cost of a 60-ml bottle with the new process is NRs 5.44 per bottle. This figure, compared with the corresponding cost in the former process (NRs 5.38 per bottle, see Section 3.4), shows that the new production process is slightly more expensive, mainly because the savings on the bleaching powder is offset by the salt, energy, capital and cleaning cost. However, since the difference is only about 1% and calculations are based on many assumptions, this is not considered particularly significant. From the point of view of the production cost, the two processes can be considered equivalent.

5.5.4 Alternative energy source cost

Although energy consumption accounts only for 0.2% of Piyush production cost (with the 60-mL packaging), ENPHO and the author considered it worthwhile to explore the possibility of installing solar panels for on-site production of energy for the generator. The main advantage envisioned would have been independence from the public supply through the grid, which is not totally reliable.

A request for quotation, including the information in Table 5.8 (theoretical conditions column), was issued to a local installer of solar panels (Lotus Energ, Kathmandu), which returned the system specifications reported in Table 5.9 (theoretical conditions column) and the quotation summarized in Table 5.10 (theoretical conditions column). The design was based on the requirements for the generator as indicated by the manufacturer (55 A and 10 V for 7 hours a day), which are different from the operational conditions that actually occurred in the trial production phase. However, even adopting the actual operational conditions, the design of the solar system is essentially the same. In fact, the transformer/rectifier is providing the generator with only a fraction of the expected current, thus the total generation time is prolonged accordingly, but the total energy consumption remains the same.

Table 5.8 – Energy requirements for the generator

Parameter	***Symbol***	***Value (theoretical conditions)***	***Value (actual conditions)***
Voltage needed	V	12 V	10 V
Current needed	A	55 A	25 A
Supply time (hours per day)	H	7.0 h	16.5 h
Autonomy days	D	3	1

Table 5.9 – Design of the solar system

Parameter / Element	***Symbol / Equation***	***Value (theoretical conditions)***	***Value (actual conditions)***
Total daily load	TDL = V x A x H	4,620 VAH	4,125 VAH
System voltage	SV (input)	12 V	12 V
Total amperhours per day	TAH = TDL / SV	385 AH	344 AH
Typical sun hours available at the site	SH (input)	4.5 h	4.5 h
Selected photovoltaic module		Siemens SP 75	Siemens SP 75
Rated current for the selected module	MA (input)	4.40 A	4.40 A
No. of photovoltaic modules	NM = TAH / (SH x MA)	19	18
Selected battery		TRO27TMHE	TRO27TMHE
Output voltage of the selected battery	BV (input)	2 V	2 V
Storage capacity of the selected battery	SC (input)	660 AH	660 AH
No. of batteries in series	NBS = V / BV	6	5
No. of batteries in parallel	NBP = (TAH x D / SC)	2	1
Tot. no. of batteries	TNB = NBS x NBP	12	5

Table 5.10 – Quotation for solar systems

Element	**Unit cost (NRs)**	**Theoretical conditions**		**Actual conditions**	
		Quantity	**Cost**	**Quantity**	**Cost**
No. of photovoltaic modules	32,590	19	619,210	18	586,620
No. of batteries	16,090	12	193,080	5	80,450
Mounting frames	8,090	4	32,360	4	32,360
Solar system manager device	17,990	3	53,970	3	53,970
Installation	5%	1	44,931	1	37,670
TOTAL SYSTEM COST (NRs)			943,551		791,070
TOTAL SYSTEM COST (US$)			**12,580**		**10,548**

The overall cost for the solar system, both for theoretical and actual conditions, is unaffordable for ENPHO. A cheaper system would be sufficient if the generator is operated only when sufficient energy is available directly from the sun, without installing storage capacity. This would imply a discontinuous generation process, carried out in four days (4.5 hours a day in order to reach the total reaction time of 16.5 hours). In this case only five panels would be required, with approximately a total cost for the system (including 5 batteries, 1 mounting frame and 1 solar system manager device) of NRs 283,000 (US$ 3,773). However, such a minimal system would be quite unreliable, since the completion of the generation process would depend on having four fully sunny days in a row.

5.6 The micro-enterprise structure

One of the main decisions ENPHO will face entering the hypochlorite market relates to the organizational structure to adopt for the Micro-Enterprise (ME) that will produce and sell Piyush. The structure adopted can be changed in the future due to new circumstances, but meanwhile it has great influence on the goals and the financial management of the ME and therefore has to be defined precisely. The Save the Children's Manual strongly suggests a clear definition of the mission, the objectives, the human resources and the accounting system of the ME, to avoid confusion with the specific goals of the NGO that created it.

First, the ME has to identify the other subjects it will interface with. These are:

- The parent NGO (ENPHO);
- Suppliers (of raw material: salt, energy, water);
- Retailers (remote or local);
- Customers (remote or local);
- Other NGO's and Disinfection Program.

As far as the relationship with ENPHO is concerned, different structures are possible. Figure 5.11, Figure 5.12, and Figure 5.13 show the three main structures.

Figure 5.11 – Micro-enterprise structure 1

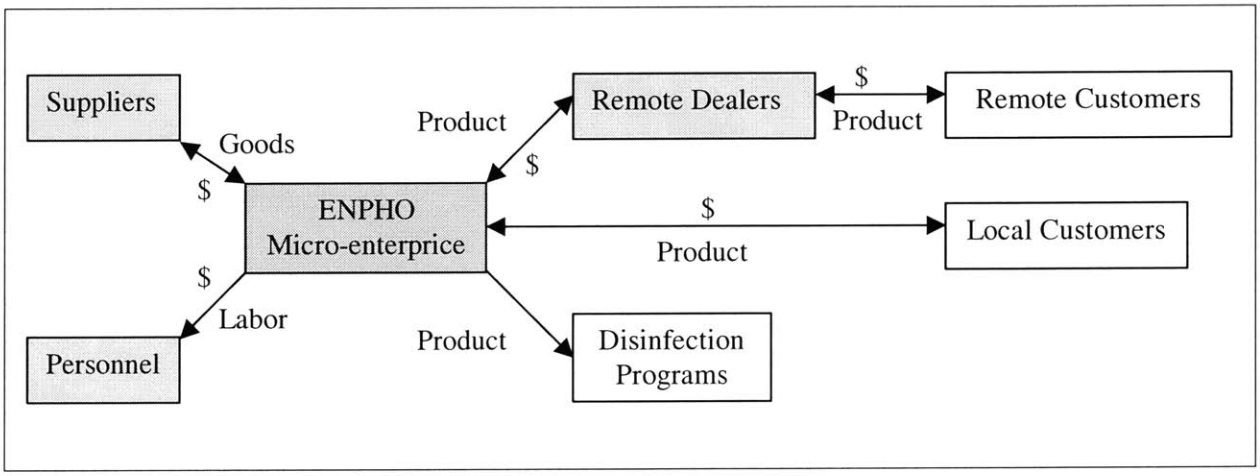


Figure 5.12 – Micro-enterprise structure 2

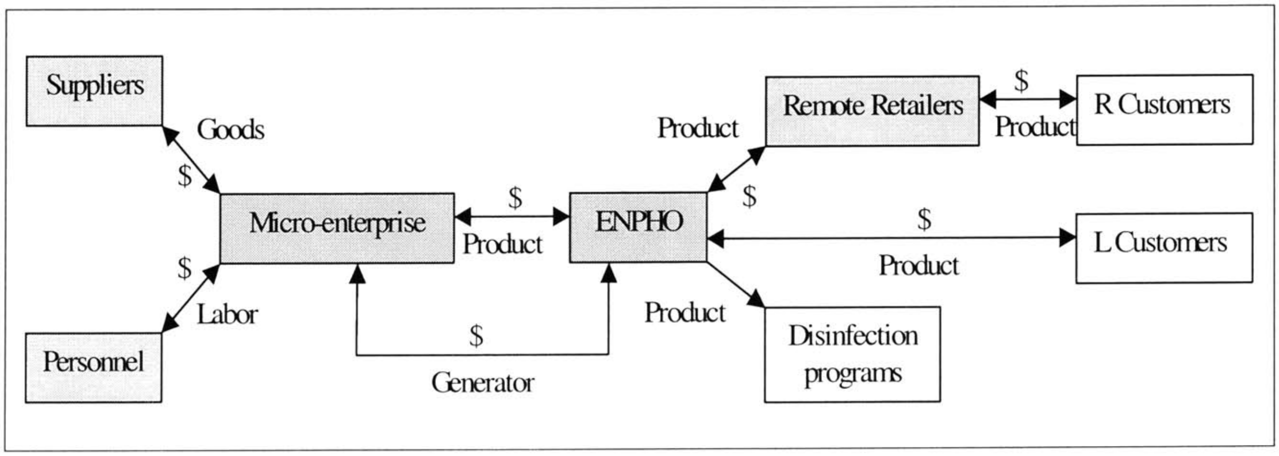
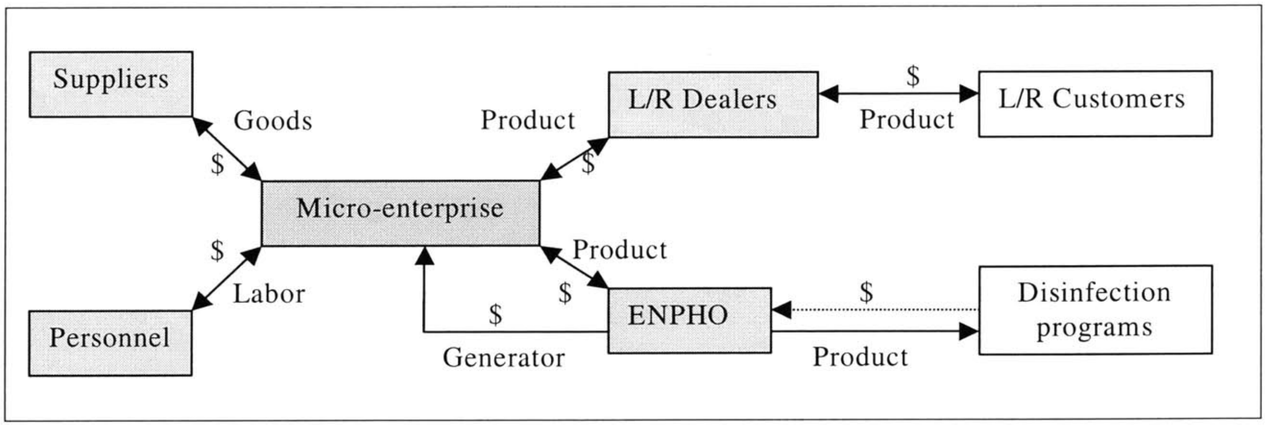


Figure 5.13 – Micro-enterprise structure 3



The first possibility is the simplest to implement and probably the most appropriate in the initial phase of business development. The ME is actually part of ENPHO (a specific division, for example) and does not have a separate accounting system. The personnel working for the ME is paid by the NGO, and costs and revenues from the hypochlorite business are accounted for in the balance sheet of the NGO. In this organizational structure, the goals for the ME are strongly dependent on the goals of the NGO. For example, if the NGO is committed to implementing disinfection programs (directly or indirectly through other NGOs), it might decide to provide Piyush to such programs at cost or even for free. This non-profit-driven approach may not allow break-even with production costs. Ultimately, the fate of the ME will depend on the decisions of the management of the NGO and, possibly, on the orientation of the donors.

Even if in this initial phase the ENPHO accounts for the ME expenses and revenues, it is important that the ME develops an independent-like accounting system, keeping track of any kind of shared resources and direct or indirect subsidy received from ENPHO. The possibility of evaluating real expenses and revenues is the basis for clearly measuring the capability of the ME to sustain itself financially. Without this transparency, the ME will not be able to move confidently to more independent organizational forms.

A second alternative sets up the ME as an independent entity and ENPHO as a supporting agency. The accounting system for the two organizations is formally separate (depending on the specific set of laws in Nepal, this means paying taxes and hiring personnel independently). In this case, ENPHO and the ME must decide about the ownership of the hypochlorite generator. It might be donated to the ME or ENPHO could lease it to the ME at a particularly favorable rate.

The support could consist in personnel and infrastructure sharing or in ENPHO acting as a wholesaler for Piyush, with a contract that guarantees to the ME a minimum yearly purchase. In this case, the ME would have a reliable source of revenue. Nevertheless, the ME would be charged with the responsibility of its own financial balance, and the management of the ME would be required to plan a sustainable production pace and recruit the needed human resources. Compared to the previous situation, in this case the ME has to be extremely careful in hiring the adequate number of personnel in order to be able to reach the targeted production within the established deadlines and the forecasted costs.

In the third case, the ME is totally independent from ENPHO, which is then treated as one possible customer. Sharing of personnel and infrastructure is still possible, but there is no specific support from the NGO in committing to buy a fixed amount of Piyush each year. In this case the ME management has even more responsibility, because the pool of customers must be sufficiently large and reliable to sustain the ME all year long. This last ME organizational structure can be also considered as the final point of a progressive evolution that the ME will pursue, along with the growth in the public acceptance of the product.

Table 5.11 summarizes the main points for each of the three possible structures.

Table 5.11 – Consequences of different micro-enterprise structures

Solution	***1***	***2***	***3***
For ME	No formally separate accounting system. Little independence in production and pricing strategies	Separate accounting system. Support from the NGO in terms of personnel and facilities sharing. Support in terms of guaranteed revenues. Responsibility of reaching break-even production	Separate accounting system Support from the NGO in terms of personnel and facilities sharing Responsibility of maintaining a sufficient production and level of sales.
For NGO	Total control of technology, production, and price. Possibility of profit.	Potential profit from generator leasing. Indirect control on production (agreement on price). Support to the ME in terms of personnel and facilities sharing.	Potential profit from generator renting. No control on production nor price. Possibility of personnel and facilities sharing.

For ME personnel	Lower risk employment	Higher risk employment	Higher risk employment
For customers	Price controlled by the NGO.	Price controlled by the NGO.	Uncontrolled price

5.7 Financial analysis

In the case of ME structure 1, for the hypochlorite business to be financially viable it is sufficient that the prices for the different Piyush forms equal the net production cost for each of them, since the fixed costs for the management salaries and the overall services are borne by ENPHO. In contrast, in ME structure 2 and 3, the ME has to determine prices and production for the various Piyush forms that allow the ME to break-even the internal costs for salaries and overhead. A minimum break-even production for each product results from the following calculation:

$$\mathrm{MBEP} = (\mathrm{OC} + \mathrm{SC}) / (\mathrm{P} - \mathrm{PC})$$

Equation 5.1 –Minimum break-even production

where:
MBEP = Minimum Break-Even Production (# of units per year)
OC = overhead costs allocated to that product (in NRs per year);
SC = salary costs (in NRs per year);
P = price for the Piyush form considered (in NRs per bottle or per liter);
PC = production cost (in NRs per bottle or per liter).

For example, if the ME has an annual overhead of NRs 50,000, salary costs of NRs 90,000, a selling price of Piyush to the NGO of NRs 15 per bottle, and a production cost of NRs 10 per bottle, the minimum number of bottles to be produced and sold per year is 28,000. In this case, it is evident that the ME is much more independent, but has to be also much more careful in the management of its resources and in the development of a sufficiently large customer base.

6. Sustainability of sodium hypochlorite generation in Nepal

The concept of sustainability is multi-faceted and complex. In this chapter, the term "sustainability" is used to indicate the durability and flexibility (sometimes referred to as "resilience") of an activity or system for an indefinitely long period of time. Since it is always difficult to make sound predictions about the distant future, sustainability is defined here to mean that the activity or system is not only capable of surviving based on existing conditions, but it is also equipped with a series of tools and skills, embedded in the system, that allows it to perceive changing conditions and elaborate autonomously new behaviors and action/reaction strategies.

To give a simple example drawn from the daily experience, an anti-virus software that has been designed to debug the existing range of known computer viruses is not sustainable, since, soon or later, a new virus, not listed in the software database, is likely to elude control and infect the system. In contrast, software equipped with a periodic self-down-loadable database up-grade is more sustainable, in the sense that is able to react effectively in a wide range of new situations.

It is evident from this example that "total" sustainability, in the sense of being able to adapt to any possible new situation, is an impossible target. However, it is possible, and extremely useful, when studying a system or an activity, to identify those factors that might likely and critically compromise proper functioning.

This chapter analyzes the sustainability of hypochlorite generation in Nepal from this perspective, highlighting potential critical factors as well as opportunities for continuous improvement. The analysis is conducted from three points of view – technical, economic, and social – that together contribute to the whole concept of sustainability[19]. In particular, sustainability is considered the result of the interaction of the elements shown in Figure 6.1, where technical viability, financial balance and social acceptability are just part of the whole system and not ultimate evaluation criteria by themselves.

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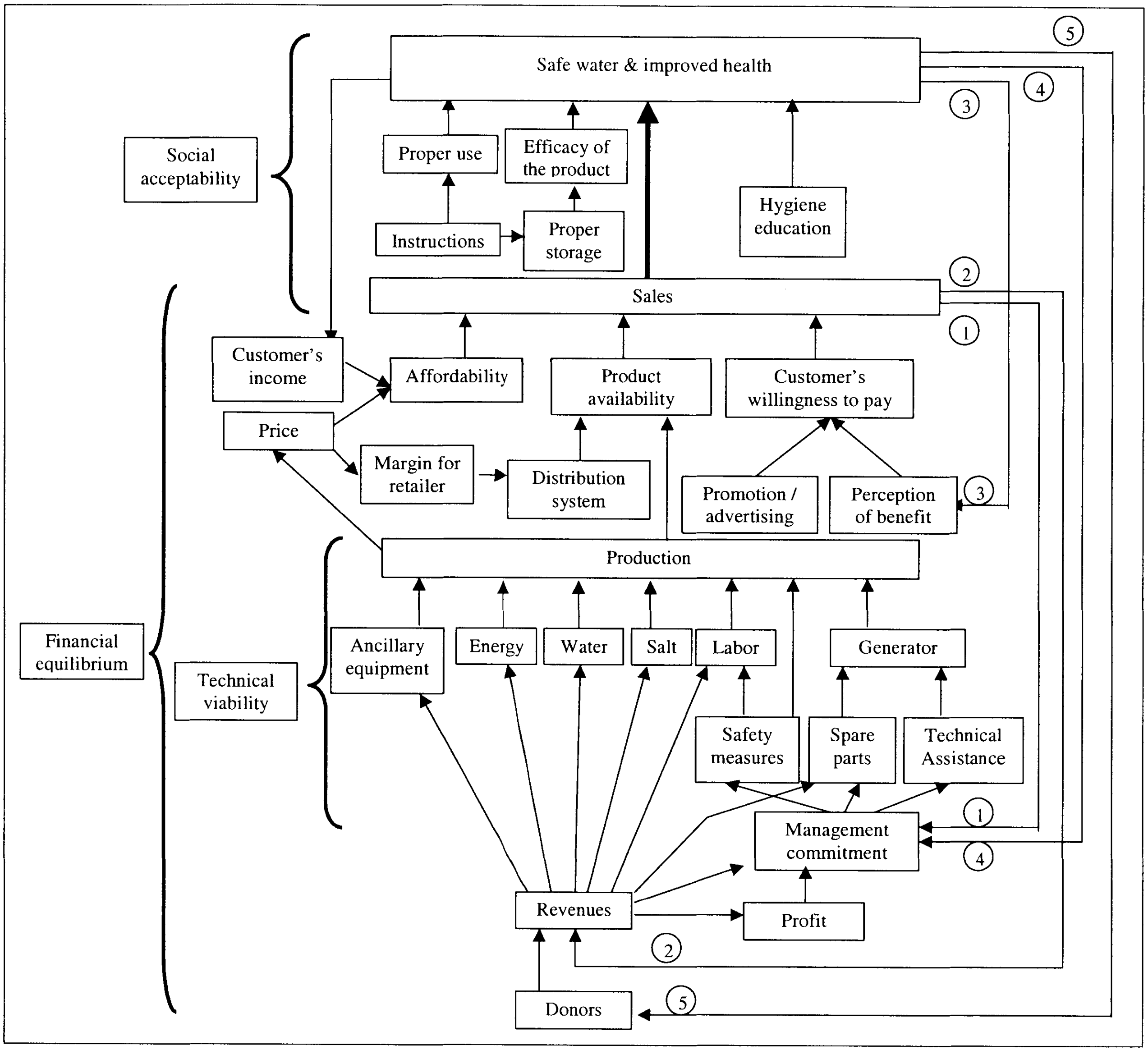
[19] A wider definition of sustainability would also include the environmental, the institutional and the legal point of view. The main idea, here, is that sustainability is the result of the reciprocal interrelation between technical feasibility, economic viability, social acceptance, environmental sensitivity, institutional consensus and legal compliance.

Figure 6.1 – Relations between sustainability factors in the hypochlorite generation business



* Numbers in the figure are intended to help in following the connection lines.

6.1 Technical feasibility

As described in Chapter 4, in January 2002, the author collaborated with a Nepalese NGO, ENPHO, in the installation and commissioning of a hypochlorite generator in Kathmandu. The set-up phase was integrated with the training of local personnel and the preparation of a procedure for the production of an officially registered hypochlorite disinfectant (Piyush).

The technical support provided by ENPHO, both in terms of materials and expertise, was fundamental for the success of the operation. The main factors that made possible a successful and quick installation of the unit and the set-up of the activity are listed in Table 6.1. The first column lists a qualitative evaluation of the relevance of each factor, based on the author's field experience. Obviously, none of the listed factors would have been sufficient alone, but they were all more or less necessary to complete the installation and set-up phase in the designated time.

The same factors will be critical in supporting hypochlorite production in the future, and, therefore, can be considered as "technical sustainability factors." In this respect, it is extremely important to assess which factors are more likely to fail or be discontinued in the future, so that preventive measures or "replacement" strategies can be planned in advance. The second column of Table 6.1 provides an evaluation of how much each factor is critical in the specific situation of Kathmandu, while the third column summarizes the preventive measures implemented to avoid or minimize potential negative effects. Lastly, the fourth column provides an evaluation of how much of the potential failure of the system depends on each factor. In the paragraphs below a rationale for these evaluations is provided.

Table 6.1 – Technical sustainability factors for hypochlorite generation in Nepal

Factor	***Relevance for the feasibility of the activity***	***Likelihood to fail or being discontinued***	***Preventive measures adopted***	***Overall risk of failure due to this factor***
Hypochlorite generator	Indispensable	High	Simple system Education	Medium
Source of water	Indispensable	High	Oversized unit Storage	Low
Source of electrical power	Indispensable	High	Oversized unit	Low
Salt	Indispensable	Low	-	Low
Commitment of the management	Indispensable	Medium	-	Medium
Commitment and skills of local personnel	High	Low	Documentation Two technicians	Low
Safety measures	High	Low	-	Low
Adequate placement	High	Low	-	Low
Expatriated technician able to install/use/test the generator	Low	Low	-	Low

Laboratory equipment to test for available chlorine concentration	Low	Low (if locally purchased)	Storage	Low
Ancillary materials (buckets, tanks, bottles, labels)	Low	Low	-	Low

6.1.1 The generator

The sodium hypochlorite generator is clearly one if not the most indispensable elements that make hypochlorite generation possible. The hypochlorite generator is also one of the most vulnerable parts of the system. In case of damage due to improper use or other accidental factors, the equipment will need to be repaired and technical assistance at the required level might not be available in Nepal. This eventuality has been minimized in the planning phase of the project by choosing a generator that is robust and simple to repair, so that it is possible to find local technicians capable of addressing at least minor problems. In addition, the proper training of the technicians who will operate the generator is supposed to minimize the risk of improper use. Nevertheless, problems on the generator unit itself are the major threat to the technical sustainability of hypochlorite generation.

6.1.2 Water and energy

Water and current are also critical factors, in the sense that they are often intermittent in Kathmandu. In fact, during the field experience in January 2002, ENPHO experienced lack of a piped water supply for several days, as well as occasional electricity blackouts, making the continuous production of hypochlorite impossible. This anticipated problem was addressed in the planning phase, when a generator capable of much larger production than the daily demand was procured. Since customer demand for hypochlorite is currently quite irregular, having periods of inactivity due to water scarcity or blackout is not a problem if a sufficient storage of hypochlorite has been arranged. In addition, ENPHO has private water storage tanks that give a moderate buffer capacity when the piped water supply is discontinued. An extreme solution, which should be evaluated from the economic point of view, is to buy water from water vendors during the dry periods.

Installing solar panels to power the generator would have been an alternative possible solution against energy blackouts. However, the investment cost, based on a quotation by a local solar panel installer, at about NRs 950,000 (US$ 12,600), is totally unaffordable for ENPHO. In addition, the use of solar panels would have added technical risk of failure, because of the use of delicate panels and batteries. The advantages would have been a lower contribution to global exploitation of non-renewable energy sources.

6.1.3 Salt

Salt is indispensable for hypochlorite generation, but since it is also an indispensable element in human nutrition and food conservation (especially in countries such as Nepal where refrigeration is not common), it is likely to always be readily available.

The testing phase has proven that both raw and refined salt are suitable for hypochlorite generation, and, therefore, a replacement is available in case of lack of one of the two types. Availability of salt does not seem to be of concern, also because it is an internal product of Nepal.

The quantity required by the unit installed is quite modest (4.5 kg per 150 liters of hypochlorite solution); therefore no preventive measures such as storage have been suggested.

6.1.4 Management commitment

From the field experience, it was quite evident that the commitment of ENPHO management is fundamental to the success of the initiative. Based on the author's experience, issues related to the installation of the unit and the organization of the operation team need a clear responsibility structure. In the specific case of ENPHO, for example, water was not readily available at the site designated for the location of the unit and the power supply was not strong enough for the unit to work continuously. An immediate intervention of ENPHO's director allowed mobilization of the human and economic resources needed for installing a tap and a new power socket close to the hypochlorite generator.

In general, hypochlorite generation, like any other technology-based activity, is likely to last if maintenance and upgrading are continuously provided. This depends mainly on financial resources and willingness-to-pay coming from the management, whose decision is usually based on the activity "results" in terms of revenues, environmental compliance and, especially for an NGO, social effectiveness. Hence, hypochlorite generation's technical sustainability in Kathmandu is strongly dependent on the sustainability of other non-technical aspects. This fact of interrelated sustainability is illustrated more in detail at the end of this chapter.

In other circumstances, it could not have been so easy to find a solution for technical problems such as insufficient water and energy availability. In rural areas of the country, electricity is much less available and, in this case, management commitment is of little relevance, since the energy supply system is usually out of the control of single individuals. Similarly, if the water source is far from the operation site or provides inadequate water quantity or quality (high turbidity or high hardness), there is little that the management can do. Determining that minimum requirements are fulfilled before starting the implementation of the project is part of a well-thought through planning process.

6.1.5 Commitment and skills of local and expatriated personnel

The commitment of the local personnel involved in the daily operation of the hypochlorite generator is also a highly relevant component of technical sustainability. In addition, specific skills in operating an electrical unit and in performing laboratory tests are required. These were available at ENPHO, and this contributed greatly to speeding up the set-up phase. In less favorable conditions, a longer training period would have been necessary to enable local personnel to perform independently all the required tests to ensure optimal production and a high quality product. However, since the technology is simple and the tests are easy, it can be taught in a reasonable amount of time, such as 1 to 4 weeks. The sustainability in this case depends on the time and the economic resources available for this longer educational phase, more than on its intrinsic technical feasibility. The willingness of management to pay for a competent technician is often more an issue than the availability of a technician itself.

Once the business activity has begun, it is unlikely that the personnel would stop their commitment, especially if monitored by aware management. Likely causes of discontinuity are limited to leave or illness of the operators. To limit this risk in the specific case of ENPHO, a detailed documentation has been provided and more than one technician has been instructed in the use of the generator. Overall, the risk of failure due to lack of personnel is considered low in the ENPHO case.

6.1.6 Safety measures

Presence of adequate safety measures has been ranked as a highly important factor in the sustainability of hypochlorite generation at ENPHO. The main reason for this is that ENPHO has a legal obligation as a laboratory in Nepal to maintain a "non hazardous activity" status. Even if safety regulations are not strictly enforced in Nepal, accidents affecting personnel, such as severe skin burns or electroshock, are likely to force the management to shut down the activity. Therefore, ensuring safe working conditions is of primary importance. The safety signs placed in the working area and the grounding of the power source were intended as measures to limit the intrinsic risks of this activity.

Specific attention to the safety was also address in the planning phase of the project, when the hypochlorite generator was chosen. In fact, the unit installed in Nepal produces a low concentration solution (0.5% of available chlorine, while the normal bleach commonly used in western countries has a 5-6% concentration of available chlorine), using normal low voltage current (220 V).

6.1.7 Adequate placement

Adequate placement of the generator has been also considered a relevant factor, for two reasons. Firstly, a properly ventilated position minimize the risk of explosions due to the hydrogen gas produced in the hypochlorite generation process (see Section 4.2.1 for more details), and therefore contributes to ensuring safe conditions for the operators. In addition, protection from the sunlight is important to maintain the targeted concentration of chlorine in the product, whose effectiveness in disinfecting water is obviously related to its commercial success. Also, the production cost of the disinfectant is effected by the time to procure water. Thus, the unit placement is important not only for technical reasons, but also for the economic viability of the activity.

In contrast, the presence of a foreign technician able to install and use the generator may be important for starting the project, but becomes irrelevant in the long terms, when the local staff is trained and capable of autonomous decisions. This fact is a fundamental component of the idea of technical sustainability: if an activity needs continuous supervision and technical assistance from foreign "experts", whose availability is at best temporary, the project is not technically sustainable. In addition, the cost of a hired technical consultant can compromise the economic sustainability of the project. Therefore, this element must be of little relevance in the long term if the project is to be sustainable.

6.1.8 Other physical components

Laboratory equipment for chlorine tests and ancillary materials such as tanks and buckets are useful for the set-up of the hypochlorite generation activity but do not contribute significantly to its sustainability. These materials can be purchased in the local market or from importers. However, their cost is relevant from the economic sustainability point of view.

Overall, it is unlikely for a hypochlorite generation project to fail because of lack of these materials.

6.2 Economic viability

Figure 6.1 shows the main relations between economic, technical and social factors involved into the Piyush business. Once the production of Piyush is established in terms of the technical elements discussed in the previous section, the main next step is to ensure the financial stability of this business.

The main criterion to evaluate economic sustainability depends on the ultimate goal of the Micro-Enterprise (ME) involved in the business, as discussed in Section 5.6. If the ME is structured as a "for-profit" enterprise, revenues from sales must be sufficient to cover the business costs and produce a profit that is satisfying for the shareholders. In contrast, having a profit is only a partial goal for social enterprises, which also seek to produce some social benefit, balancing the two goals in a double bottom line accounting system. For pure "non-for-profit" enterprises, profit is not a goal at all and the financial balance between costs and available resources, which can both be provided by the business itself or external donors, is a constraint rather than an objective. Therefore, in a for-profit enterprise, management and shareholders commitment in the business will depend mainly on the results in terms of profit, while in a non-for-profit enterprise, the main feedback comes from the social effect of the business, which can be measured directly or, more likely, is assumed to be some how proportional to the coverage of the distributed product or the provided service. These three types of feedbacks are shown in Figure 6.1, where the commitment of the enterprise management is linked to profit, to sales (connecting line #1) or, for the specific case of Piyush, to safe water and improved health (connecting line #4).

Many different factors determine the volume of sales. Some of them depend on the producer, others on the customers; others are at the interface between them.

The main component on the producer side is the issue of accessibility to the product: to boost accessibility, the producer must establish a distribution system that reaches the largest possible pool of potential customers. On the consumers' side, the main factors are their willingness to pay and the capability of paying (affordability). While the latter is indirectly measured by their income, the former depends on many cultural and psychological factors, which require deep study to be assessed precisely. The price of the product is placed at the interface between the producer, retailers and the customers. It must provide the desired financial result for the producer, must ensure a profit for the retailers, and must agree with what customers can afford.

Specifically for a product such as Piyush, the willingness to pay is likely to depend on the perception the customers have of the health benefit produced by this product. This perception is related to the actual health benefit the customer experiences due to the use of the product. It also depends, to a certain extent, on the consciousness of the cause-effect relationship between water disinfection and improved health. A typical tool to increase this consciousness is "social marketing", which is discussed in the following section.

6.3 Social acceptability

Public acceptance of Piyush is a fundamental element in the business ENPHO (or a ENPHO-derived micro-enterprise) is going to undertake for two reasons: if people are not interested in it and the product fails in providing the desired health improvement, not only the financial balance is compromised but also the whole social purpose of this business is lost.

Availability of the product on the market is not sufficient to produce a health benefit if two additional elements are not added: (1) proper use and storage of the product, and (2) hygiene education. Proper use and storage have been addressed providing easily understandable instructions printed on the bottle label. In particular proper storage is indispensable to preserve the efficacy of the hypochlorite solution, on which the disinfectant action ultimately relies. Hygiene education is a critical co-factor for ensuring safe drinking water and improved health. In fact, water disinfection is not sufficient if re-contamination occurs or if other disease transmission pathways are not addressed at the same time.

Unfortunately, an evident health improvement depends on a complex mix of factors (hygiene, nutrition, sanitation habits) of which safe water is only a single component. The challenge, in promoting Piyush, is to give people a clue of this complex mix, stressing the fact that safe water is an important but not resolving element, so that people will not stop from buying Piyush if they do not see immediate health benefit. To this purpose, bundling Piyush supply with a water monitoring service may reinforce the idea in the customer mind that Piyush is at least effective in providing safe water, even if improved health affect are not totally evident.

A survey conducted on the Lumbini Chlorination Pilot Project in January 2002 reveals that people are satisfied with Piyush and chlorine taste is not an issue (Sullivan, 2002). However, not all the household involved in the Pilot Project continued to use Piyush. The reasons for these defaults have to be identified and addressed through specific educational and promotional tools.

7. Conclusions and recommendations

The research presented in this thesis focuses on the technical and economic issues of implementing a sodium hypochlorite generation program in a developing country. The implementation of such a program in Nepal in January 2002, in collaboration with ENPHO, a Kathmandu-based NGO, was the occasion to verify its actual technical feasibility and to create a draft business plan for a micro-enterprise that will produce, promote and distribute a sodium hypochlorite disinfectant (Piyush) for household drinking water treatment.

The technical part of the program can be considered successfully concluded, since the generator SANILEC-6 donated by Severn Trent De Nora for that purpose is now installed at ENPHO's lab in Kathmandu. ENPHO's designated personnel are able to operate the unit properly and the management is aware of all the procedures for planning its use, carrying out the necessary maintenance and facing possible technical problems. The recommendations listed in Section 7.1 represent a synthesis of the know-how gained during the set-up and testing phase carried out in January 2002.

On the economic side, the author collected information on the costs for Piyush production and the conditions of the disinfection market in Nepal. A preliminary Business Plan is presented in Chapter 5 to guide the micro-enterprise that will produce Piyush and develop the sodium hypochlorite disinfection business in Nepal. The next logical step is for the new micro-enterprise to review, modify, improve and hopefully adopt a final Business Plan, having shaped it on the basis of additional information collected on the field, and choose between the different suggested strategies for developing the business (or elaborate new ones using the suggested frameworks) and finally implement them. In Section 7.2, the main points for the success of the business development are highlighted. The final goal to implement a successful Business Plan is beyond the scope of this thesis.

7.1 Recommendations on the Piyush production process

- Proper placement of the generator is fundamental to make its use easy, safe, and efficient. The current location on the terrace at ENPHO seems to meet all the relevant requirements, apart from protection against sunlight, which is detrimental for the stability of the produced hypochlorite solution. In addition, direct light and heat in the hot season are likely to annoy the operators. Therefore, a curtain should be placed on the open side of the production area. In the future, if the production area has to be changed, refer to Section 4.2 for the main factors to be considered in the evaluation of the new place and for the suggested installation procedure.

- Plan the production cycle in advance, so that it can be run in automatic during night hours and day hours can be used for bottling the freshly made sodium hypochlorite solution.
- In the production process, refined salt is preferred because it results in a clear disinfectant solution. The higher cost of refined salt with respect to raw salt causes a minimal difference in the production cost (+2% for the bulk solution, insignificant for the bottled product). On the other hand, use of demineralized water (that was common habit in the former production process) is not necessary, as far as chemically drinkable water is used.
- Maintain the generator properly, regularly performing the cleaning procedure and avoiding dust and direct sunlight on the electrolytic cell and on the transformer/rectifier.
- Maintain proper safety conditions in the production area and respect the safety signs.
- The overall quality (and in particular the stability) of the sodium hypochlorite solution must be the main concern in the production and bottling process. Only a stable solution will provide customers with an effective and reliable product. The following recommendations are intended specifically to ensure high quality to Piyush:
  - Clean the containers used to prepare the brine solution, the reaction tank and the electrolytic cell from dirt and dust before use.
  - Analyze the water used to produce the hypochlorite solution periodically (once every 3 months), in order to keep track of the possible source of decay problems.
  - Check that no metallic parts (in the spigot or the tank lid) are in contact with the hypochlorite solution, since hypochlorite is highly corrosive and iron ions in the solution accelerate the decay process.
  - Target an available chlorine concentration in the bulk solution of 0.56% (the required reaction time will be around 17.5 hours at ENPHO, if the transformer/rectifier supplies current at about 25 A). This concentration will guarantee that, after bottling, only 5% of

the bottles will have an available chlorine concentration below the nominal concentration of 0.50% shown on the bottle label (see Section 4.3.6 and Appendix G for the explanation).

- Add sodium hydroxide (NaOH) in the freshly made sodium hypochlorite in order to raise pH above 11 (60 g per 100 L should be enough). High pH will maintain the decay process at a minimal level.
- If possible, adopt bottles with walls thicker than the ones currently used, made of brown or blue plastic.
- If the same bottles available in January 2002 are used, check that each individual bottle has sufficiently think walls. If the liquid level is easily visible through the plastic, the bottle will not provide sufficient protection against light and the solution is likely to decay more rapidly. Defective bottles must be discarded.
- If possible, bottle the fresh hypochlorite solution immediately after the production cycle is complete and store bottles in a cool place, protected from direct sunlight.
- Place full bottles and other storage containers in a clean place, protected from direct sunlight and dust.
- Keep and store appropriately samples of solutions and some bottles from each batch in order to test for decay and for future reference.

Lastly, additional research is needed in the following areas, in order to further improve the quality of Piyush and its effectiveness for customers.

- Investigate the decay rate of the alkalinized Piyush in order to assess if a shorter period is more appropriate than the current one year product life.
- Survey chlorine demand in monsoon season in rural areas. If water chlorine demand is significantly higher than 0.55 mg/L, which is the current assumption for the suggested 3-drops-per-liter dosage, the dosage instruction must be changed accordingly, in order to reach the targeted free residual chlorine value of 0.2 mg/L. Dosage of Piyush larger than what is currently suggested will make the existing bottle too small to maintain a convenient frequency of purchase for customers (about once or twice a month). Therefore, the size of the bottle may need to be adjusted accordingly (refer to Section 5.5.2 for the implications of bottle size on the unit price).

- To facilitate dosage in 10- and 20-liter water storage vessels, a new measuring cap with the appropriate capacity should replace the existing bottle cap. Size of the cap must reflect the dosage actually needed for the most commonly used water storage vessels (for example, the existing cap contains the right amount of solution for disinfecting 20 liters of water with a chlorine demand about 0.5 mg/L, but it will be inadequate if chlorine demand is higher or water storage volume is larger).

7.2 *Recommendations on Piyush business plan*

- Identify the market segments (from the categories listed in Table 5.3) that are more promising for quantity required and payment trustworthiness and try to establish medium term contracts (6 months – 1 year) that can provide stable revenues to the micro-enterprise. Possible targets are:
  - NGOs willing to use Piyush for household disinfection programs (for example CARE, which already promoted sodium hypochlorite disinfection in Kenya, Zambia and Madagascar).
  - Schools and hospitals in the Kathmandu area that can be interested not only to the disinfectant supply but also to a comprehensive water treatment and monitoring service.
- Once a solid basis with a few large, reliable customers has been established, the household segment, which is more dispersed and requires consistent promotion and distribution effort, can also be targeted.
- Identify for household customers in the rural areas the most appropriate bottle size, taking into account chlorine demand and daily volume of the water to be treated, and frequency of supply and purchase. Consider that larger containers result in lower production cost per unit volume of disinfectant.
- Find existing distribution channels (ex. Coca Cola), in order to minimize distribution cost. Consider bundling Piyush distribution and promotion with other water treatment technologies (ex. terracotta filters).
- Promote Piyush in rural areas through social marketing, education programs and community participation, possibly involving local formal or informal retailers who also work as

educators. Consider existing networks of social workers, women groups and community motivators.

- Adopt, from the outset, a transparent accounting system for the micro-enterprise, in order to identify direct and indirect subsidies coming from or to ENPHO. Only if all fixed and operative costs, and direct and indirect revenues are clearly accounted for will it be possible to precisely determine when the micro-enterprise has reached a sufficient sales level to be self-sustaining and independent from external support.
- Promote sequential use of biosand or terracotta filtration and chlorine disinfection, in order to reduce turbidity, chlorine demand, formation of disinfection by-products, and risks of diseases by protozoa (e.g. *Cryptosporidium* cysts) that are unaffected by chlorination. Further investigations on the presence of *Cryptosporidium* in fresh water sources and its role in contributing to high levels of waterborne diarrhea in Nepal are suggested.

In conclusion, it is important to notice that both technical and economic conditions in the sodium hypochlorite business are subject to change and therefore an exhaustive review of them is impossible. However, if the managers of the Piyush micro-enterprise understand clearly the role of the different components of the technical system as well as the dynamics of the business environment, they will be able to make the right choices and adapt their strategies to new scenarios, providing long term sustainability to their activity. The information and the logical frameworks presented in this thesis aimed to contribute, at least in part, to this purpose.

APPENDIX A

SANILEC-6 GENERATOR SET-UP PROCEDURE

1. Provide appropriate placement:
   a. Sufficient space (at least 3x3 m) with a cool area for storage
   b. Ventilation
   c. Chemically resistant floor (concrete, tiles, ground)
   d. Protected from direct sunlight and excessive heat
   e. Close to a power source (grid or solar system)
   f. Close to a water source (easily accessible, with sufficient production)
   g. Safe against stealing
2. Check quality of water:
   a. Low turbidity
   b. Low hardness
   c. Low color (visibly "clean" water)
3. Provide a secure wastewater discharge
4. Check for ground connection of the power source
5. Prepare and place safety signs
   a. No smoking
   b. Wear gloves and goggles when handling hypochlorite solution
   c. Caution when operating the transformer/rectifier
6. Provide a reaction tank with adequate size
7. Install a corrosion resistant spigot at the bottom of the tank
8. Provide salt
9. Run one or more pilot cycles according to the Production Procedure (Appendix C) and check performances. Adjust settings (time and/or salt) accordingly.

APPENDIX B

MATERIALS REQUIRED FOR SODIUM HYPOCHLORITE ON-SITE GENERATION

The following items are required in the production process of sodium hypochlorite with a SANILEC-6 hypochlorite generator:

1. Water
2. Common salt (sodium chloride),
3. A scale (for measuring the required quantity of salt),
4. An AC or DC power source,
5. A reaction tank with plastic spigot,
6. A plastic or wood stick (for stirring the brine solution),
7. A storage tank (optional),
8. Laboratory equipment to test for available chlorine concentration,
9. Containers (for bottling),
10. Diluted acetic acid (5% vol.) or vinegar (for the cleaning procedure).

APPENDIX C

PIYUSH PRODUCTION PROCEDURE

For the production of 150 L of 0.5 % available chlorine solution

1. Buy 4.5 kg of salt (possibly refined).
2. Rinse the reaction tank (at ENPHO this is the blue tank) and the buckets.
3. Dissolve the salt in the buckets using tap water (if granular salt is used, allow 60 minutes for impurities to settle).
4. Fill up the reaction tank to the 150-Liters mark.
5. Check that the tee-base is properly twisted on the generator cell tip.
6. Sink the generator in the reaction tank.
7. Check that the water level is at the half point of the slots.
8. Plug in the rectifier power socket.
9. Turn on the rectifier power switch.
10. Set timer (17.5 h for a 0.56% solution).
11. Press the yellow "RESET" button.
12. Check that voltage is 10 V and current is 25 A.
13. When the cycle is finished, turn off the power switch and unplug the rectifier.
14. Test for the available chlorine concentration.
15. If the concentration is below the target value, run the reaction cycle for additional time.
16. When the target concentration is reached, take out the generator cell from the tank and rinse it with clean water.
17. Store the hypochlorite solution in closed containers away from heat and direct sunlight.
18. Bottle and label solution as soon as possible. Store bottles in a cool and protected place.
19. Test for available chlorine concentration from at least 15 bottle from the same batch for quality control.

APPENDIX D

CLEANING PROCEDURE

Adapted from SANILEC® 2-6 Instruction Manual

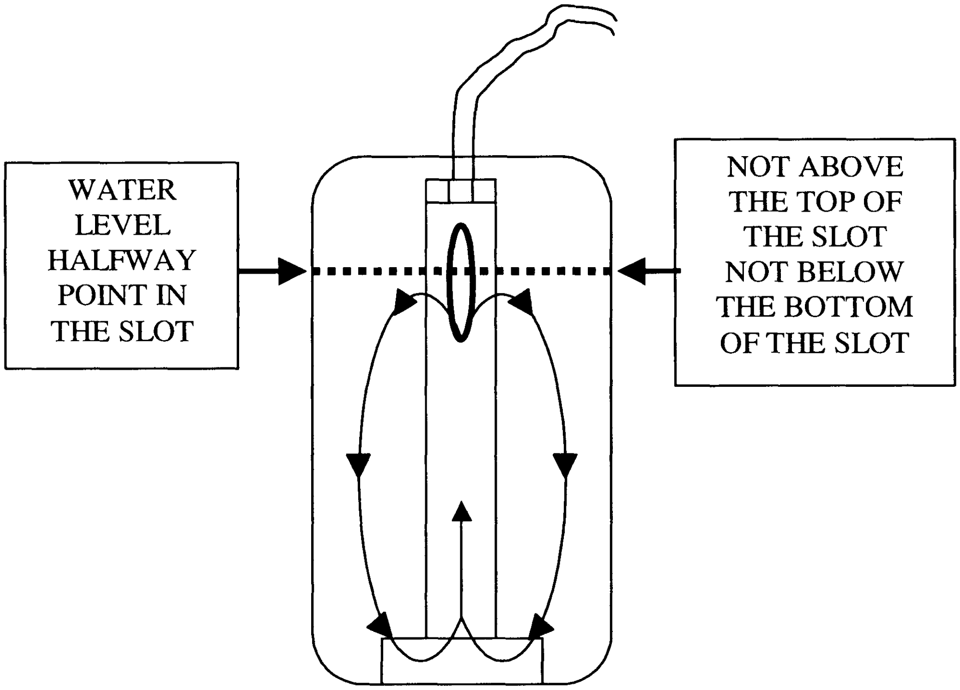
1. Unplug the transformer/rectifier from the power source.
2. Rinse the cell thoroughly with clean water.
3. Remove the tee-base from the cell.
4. Wrap cell threads with Teflon tape.
5. Attach 3" PVC cleaning cap, tightening until hand tight.
6. Pour acetic acid or vinegar into the cell through circulation slots, until it begins running out of the slots.
7. Allow unit to stand for 30 minutes with acetic acid or vinegar contained inside.
8. Empty contents of cell and refill with fresh acetic acid or vinegar.
9. Allow unit to stand for additional 30 minutes with acetic acid or vinegar inside it.
10. Empty contents, remove cleaning cap and rinse cell thoroughly with clean water.
11. Replace the tee-base, tightening until hand tight.

APPENDIX E

PRECAUTIONS

NEVER OPERATE THE GENERATOR UNLESS THE CELL IS SUBMERGED IN THE BRINE SOLUTION

ALWAYS FILL THE TANK SO THAT THE WATER LEVEL IS AT THE HALFWAY POINT OF THE SLOT IN THE CELL



BE CAREFUL WHEN BOTTLING:
IF SODIUM HYPOCHLORITE TOUCHES SKIN OR EYES, RINSE IMMEDIATELY WITH LARGE AMOUNTS OF FRESH WATER

BE CAREFUL WHEN OPERATING THE TRANSFORMER/RECTIFIER:
KEEP ALWAYS THE TRANSFORMER/RECTIFIER IN THE OFF POSITION UNLESS RUNNING A PRODUCTION CYCLE

KEEP THE TRANSFORMER/RECTIFIER AND THE CELL PROTECTED FROM HEAT, DIRECT SUNLIGHT, RAIN AND DUST

CLEAN THE UNIT WITH ACETIC ACID OR VINEGAR
AT LEAST ONCE EVERY 7 PRODUCTION CYCLES (100 hours)

APPENDIX F

PROCEDURE TO ASSESS CHLORINE DEMAND IN HOUSEHOLD DRINKING WATER

Adapted from CDC (2002c).

Rationale

The dose of disinfectant must be determined using the locally available product with the locally available water in the adopted vessel because different waters require different doses of sodium hypochlorite for adequate disinfection. This is best accomplished via trial and error, measuring free chlorine levels one half hour after dosing.

Procedure

1. Add a known amount of disinfectant (for example 1 capful) to the vessel;
2. After half hour, measure the free chlorine concentration;
3. If free chlorine level is between 0.5 and 2.0 mg/L, the dose is adequate. If it is lower/higher, repeat step 1 using an incremented/decremented dose of ½ capful to the vessel until the correct chlorine level is achieved in the stored water.

Note

The cap of the disinfectant bottle should facilitate measuring the correct amount of disinfectant for the water storage container. For a 20-liter water vessel, the required dose of a 0.5% available chlorine disinfectant will likely be between 5 and 10 ml; therefore a cap size of approximately 2.5 to 10 ml will work best (with a corresponding dosage instruction between 1 and 4 capfuls).

APPENDIX G

STATISTICS FOR QUALITY CONTROL

Given a sample of N bottles of Piyush, it might be necessary to determine statistics for some characteristic X of the bottles in the sample (it could be the weight or the available chlorine concentration), in order to check for compliance to pre-assigned requirements.

The mean, M(X), and the standard deviation, S(X), for the sample are defined as:

$$\boxed{M(X) = \frac{1}{N}\sum_{i=1}^{N} x_i} \qquad \boxed{S(X) = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - M(X))^2}}$$

where x_i are the values observed in the sample.

Assuming that the characteristic X is distributed in the population of bottles according to a Normal distribution[1] with unknown parameters μ (mean) and σ (standard deviation), M(X) and S(X) are good estimators of these parameters and can be used to evaluate the probability of μ and σ falling in given intervals.

In particular, the following calculation can be used:

1. To determine the confidence interval for the mean μ of the population, when the standard deviation σ of the population is known, with an α confidence level (α usually 95%):
   - Calculate $z(1-\frac{\alpha}{2})$ (inverse of the normal distribution) using normal distribution tables;
   - Calculate the radius of the confidence interval: $r = z(1-\frac{\alpha}{2}) \cdot \frac{\sigma}{\sqrt{N}}$

---

[1] In statistics, the normal distribution is a frequency distribution in the shape of the classic bell curve. It accurately represents most variations in such attributes as height and weight. Any random variable with a normal distribution has a mean and a standard deviation that indicates how much the data as a whole deviate from the mean. The standard deviation is smaller for data clustered closely around the mean value and larger for more dispersed data sets (On-line Encyclopaedia Britannica).

- The confidence interval is $[M(X)-r, M(X)+r]$, that means that μ falls in this interval with a probability P= (1 – α).

2. To determine the confidence interval for the mean μ of the population, when the standard deviation σ of the population is <u>not</u> known, with an α confidence level (α usually 95%):
   - Calculate $t(1-\frac{\alpha}{2})$ (inverse of the student-t[2] distribution) using student-t distribution tables and N-1 degrees of freedom;
   - Calculate the radius of the confidence interval: $\mathrm{r} = \mathrm{t}(1 - \frac{\alpha}{2}) \cdot \frac{S}{\sqrt{N}}$
   - The confidence interval is $[M(X)-r, M(X)+r]$, that means that μ falls in this in this interval with a probability P= (1 – α).
3. To determine the confidence interval (upper limit) for the standard deviation σ of the population, with an α confidence level (α usually 95%):
   - Calculate $q(1-\alpha)$ (inverse of the χ^2 distribution) using χ^2 distribution tables and N-1 degrees of freedom;
   - The confidence interval is $[0, \sqrt{\frac{N-1}{\mathrm{q}}} \cdot S]$, that means that σ falls in this in this interval with a probability P= (1 – α).
4. To determine the number of samples to be analyzed, in order to achieve a given level of precision r in the measurement of the mean μ of the population, at a given α confidence level (α usually 95%), if the standard deviation σ of the population is known:
   - Calculate $z(1-\frac{\alpha}{2})$ (inverse of the normal distribution) using normal distribution tables;

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[2] The student-t distribution, or simply t-distribution, is a symmetric distribution that describes the probability associated with a variable $t = \frac{\overline{X} - \mu}{\sigma / \sqrt{n}}$ where X is the sample mean of a sample of n elements taken from a Normal population with mean μ and standard deviation σ.

- The number of samples to be tested is $N = \left(\frac{\sigma \cdot z(1-\frac{\alpha}{2})}{r} \right)^2$.

For example, let's assume that the standard deviation σ of the available chlorine concentration in Piyush bottles is 400 mg/L. We want to determine the number of bottles we need to test in order to have a 95% confidence level that the mean μ of the concentration in the whole population of bottles is within the interval [5,000 –5,400] mg/L, i.e. the precision is ± 200 mg/L around the mean value of 5,200 mg/L. According to the above equations and the normal distribution tables:

$$z(1-\frac{\alpha}{2}) = z(1-\frac{0.05}{2}) = z(0.975) = 1.96 \qquad N = \left(\frac{\sigma \cdot z(1-\frac{\alpha}{2})}{r} \right)^2 = \left(\frac{400 \cdot 1.96}{200} \right)^2 = 15$$

5. To determine the value X* to target in order to have the characteristics X above a given threshold X_{min}, at given α confidence level (α usually 95%), if the standard deviation σ of the population is known:
    - Calculate $z(1-\alpha)$ (inverse of the normal distribution) using normal distribution tables;
    - The target value is $X^* = X_{\min} + \sigma \cdot z(1-\alpha)$.

    For example, let's assume that the standard deviation σ of the available chlorine concentration in Piyush bottles is 400 mg/L. We want to determine the concentration to target in preparing the bottles, in order to have a 95% confidence level that the concentration in the whole population of bottles is above the lower limit of 5,000 mg/L, i.e. only 5% of the bottles have an available chlorine concentration below the limit. According to the above equations and the normal distribution tables:

    $$z(1-\alpha) = z(1-0.05) = z(0.95) = 1.645$$

    $$X^* = X_{\min} + \sigma \cdot z(1-\alpha) = 5{,}000 + 400 \cdot 1.645 = 5{,}660$$

    The available chlorine concentration to target is 5,660 mg/L, i.e. 0.56%.

APPENDIX H

REPRODUCTION OF THE PIYUSH.XLS SPREADSHEETS FOR PIYUSH PRODUCTION PLANNING

Calculations for Planning Piyush Production Frequency

Input data only in the cells with shaded background

	Unit	*Quantity*	*Notes*
Concentration of disinfectant	%	0.5	
Concentration of disinfectant	mg AVC /L	5,000	AVC = AVailable Chlorine
Residual free chlorine targeted	mg RFC /L	0.20	RFC = Residual Free Chlorine
Chlorine demand	mg CHD /L	0.55	CLD = CHlorine Demand (depends on water quality)
Chlorine dosage	mg/L	0.8	
Dose of disinfectant	mL/L	0.2	
Dose of disinfectant	drops/L	3.0	
Disinfectant available	L/d	150	depends on production: SANILEC 6 = 150 L per day
Water treatable	L/d	1,000,000	
Water treated per household	L/d/HH	50	depends on household size and habits
Household potentially served	HH	20,000	
Average size of an household	ca/HH	6	
Population served	ca	120,000	
Actual number of household served	HH	4000	
Required frequency of production	# per week	1	must be less than 6 (one day for cleaning)
Bottle size	mL	60	
Quantity of water treated with a bottle	L	400	
Duration of a bottle	day	8	
Required frequency of purchase per HH	# per month	4	must be 1 or 2 (depending on ease of supply)

Calculations for Planning Piyush Production Cycle

Input data only in the cells with shaded background

	Unit	*Quantity*	*Notes*
Total solution to be produced	L	140	
Final hypochlorite concentration	mg/L	5600	The concentration must be below 8000 mg/L
	%	0.56%	
Margine for leakages and spills	-	5%	
Total volume of water needed	L	147	
Water for each cycle	L	150	Water level must reach the generator slot
Number of production cycles	-	1	
Salt for each cycle	kg	4.5	Theoretical value: 30 g per liter
Total amount of salt to purchase	kg	4.5	
Current	A	25	Theoretical value: 55 A.
Time for each cycle	h	17.6	

APPENDIX I

MODEL FOR COMPARING THE COST FOR THE USERS OF DIFFERENT DISINFECTION SYSTEMS

Family Demand	*Unit*	*Value*
Number of family members	members	6
Specific Water Demand	L/d/mb.	6.0
Daily Water Demand	L/d	36
Assumed exchange rate for US$	75	NRs

Base Case: Chlorine Disinfection	*Unit*	*Value*
(using Piyush)		
Chlorine dosage	mg Cl2/L	1.0
Daily Chlorine Demand	mg Cl2/d	36
Chlorine solution concentration	mg Cl2/L	5,000
Daily chlorine solution Demand	mL/d	7.2
Yearly chlorine solution Demand	L/y	2.6
Chlorine solution bottle volume	mL	60
Yearly chlorine bottle demand	#/y	44
Bottle price	NRs/bot.	17
Yearly Family Chlorine Expense	NRs/y	**748**
	US$/y	10.0

Alternative 1: Filtration	*Unit*	*Value*
(using an Indian candle filter)		
Number of candles per filter	#	2
Number of filters per family	#	1
Average life of a filter	y	2
Average life of a candle	y	1
Cost of a candle filter	NRs	300
Cost of a candle	NRs	35
Flowrate	L/h	3
Time for filtering	h/d	12
Yearly Family Filtration Expense	NRs/y	**220**
	US$/y	2.9

Alternative 2: Boiling	*Unit*	*Value*
(using a kerosene stove)		
Quantity of water treated per cycle	L/cycle	5.0
# of cycles	cycle/d	7.2
Boiling cycle duration	min./cycle	30.0
Daily boiling time	min./d	216.0
Specific fuel consumption	L/h	0.120
Daily fuel consumption	L/d	0.43
Yearly fuel consumption	L/y	158
Fuel cost (kerosene)	NRs/L	10
Yearly Family Fuel Expense	NRs/y	**1,577**
	US$/y	21.0

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