INTERNATIONAL JOURNAL OF ENVIRONMENT

Volume-4, Issue-1, Dec-Feb 2014/15 **ISSN 2091-2854**

Received:20 July *Revised:19 September* *Accepted:9 February*

PCBS CONTAMINATION AMONG DISTRIBUTION TRANSFORMERS IN THE KATHMANDU VALLEY

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Abstract

Transformer is the crucial part in any electrical system, however there are many risks associated with its use. Thus this study was focused on assessing the status of PCBs contamination and distribution of transformers in Distribution Centre-North of the Kathmandu valley along with PCBs contamination in them. Each transformer within the study area was closely observed to obtain information about all transformers. The dielectric oil samples from the transformers were collected, safely stored and analyzed in Test Kits (L2000DX Chloride Analyzer System, recommended by UNEP). Among 111 samples of transformer oil analyzed, 4 transformers were found PCBs contaminated and they were manufactured before 1990s. The total amount of PCBs contaminated transformer oil in these transformers was 479.6 Kg. Seven transformers were found leaking, four transformers located at residential area were found emitting a low frequency tonal noise, two transformers were located within school compound, nine transformers were located near water body and around 1.44 square meters of soil surface was found contaminated by transformer oil. Though there is no way to eliminate all the risk and consequences of operating oil filled transformers, scientific distribution and proper handling could be the reasonable approaches to reduce the risks.

Key Words: Distribution Centers (DCs), Feeder, Leak, Polychlorinated biphenyls (PCBs), Sub Stations (SS)

Introduction

Transformers are devices that can increase or decrease the voltage level of an electrical current. This is important because transfer of electrical energy is much more advantageous when the voltage is maintained at a high level; this is because energy losses are much lower at higher voltages, however the voltage must be decreased before use, so as to correspond to industrial requirements of possibly a few thousand volts, or to domestic requirements of a few hundred volts (Thomas 1993); therefore, transformers are essential parts in the power system for voltage level conversion and maintaining the power flow. They are applied at following four major regions (Willis *et al.*, 2001). First at power plants, where power is generated and raised to transmission; second at switching stations, where the transmission voltage is increased; third at distribution substations, where the incoming transmission-level voltage is reduced to distribution voltage generally known as power transformers; and fourth at service transformers, where the voltage is reduced to utilization level for routing into consumers' homes and businesses generally known as distribution transformers (DTs).

Fig 1: Leaking Transformer

However DTs may suffer from several conditions such as overload conditions, which might lead to transformer failures. The main causes include insulation failure, design/material/workmanship, oil quality and contamination, overloading, fire/explosion, line surge, improper maintenance/operation, flood, loose connection, lightning and moisture. All such causes may result to the leaks in transformers (Bartley, 2003). When a leak or seepage has been detected on a transformer, it is necessary to immidately establish the cause of the leak, contain the oil leaks and take remedial action.

PCBs mixed oils were initially proposed as dielectric fluids for use in electrical transformers because of their excellent dielectric properties, low volatility, good viscosity, good fire resistance, low water solubility, high solubility in organic solvents, and good anti-ageing properties, with no deterioration during service. The commercial production of PCBs started in late 1930s and since then it has been used in transformer oil. When PCBs contaminated transformer fluid burns, very toxic chemicals like dibenzofurans are formed, and they have deleterious effects on health. Apart from the danger of PCBs producing furans in the case of fires, PCBs themselves are hazardous substances because of their high toxicity, great stability, high solubility and bioaccumulation in the fatty tissues of humans and animals. PCBs concentrations can then build up in the body, for example in the fat, the liver, etc., and these molecules are very difficult to eliminate (Safe *et al.*, 1985). Due to having such impacts, PCBs were gradually phased out for applications in transformers from the early 1980s, depending on the country. PCB was produced and used in transformers till 1990, and thus equipment manufactured till 1990 may contain PCBs. However, very large number of transformers may still contain and may have been the source of cross-contamination of PCBs even today. The main risks from these transformers are leaking of PCBs oils into the environment and increased difficulty in the management after the end of the working life of the transformers.

Materials and Methods

This research was carried out in Nepal Electricity Authority, Distribution Center-North of the Kathmandu valley, where 232 distribution transformers were connected to 30545 households (NEA, 2011).

Both analytical and descriptive method was used for the study. Analytical method was used to analyze the degree and extent of PCBs contamination in transformer oil using L2000DX Chloride Analyzer System [UNEP recommended test kits]. Out of 232 distribution transformers of Distribution Center-North (NEA, 2011), 89 percent of transformers (207 transformers) were accessed for the study but oil samples from 54 percentage of them, manufactured till 2005 were selected for study. The transformer oil from these transformers was analyzed for PCBs contamination because they were either manufactured before 11990 or suspected of PCBs cross contamination during maintenance works. Each transformer was given separate ID number in order to avoid error; e.g. ID number was given as TdKN0001, where Td indicates distribution transformer, KN indicates Kathmandu North Distribution center and 0001 indicates first visited transformer. For the analysis of transformer oil sample in L2000DX, first PCBs/ (chlorinated organic) in the sample were chemically converted to chlorine (Dexsil Corporation, 2006). Reagents were used in such a way that all the chlorinated cyclic content, which is PCBs, of the transformer oil would be converted to chlorine ions when the reaction completes. On completion of the reaction the solution was filtered. The final solution obtained thus would fully contain a PCBs equivalent chloride ion. This chloride ion content in the final extract was then quantified using a chloride specific electrode and converted to an equivalent analyte concentration (i.e. PCBs) using the conversion factors programmed into the analysis instrument.

Descriptive method was done through field observation, where each and every transformer within the study area was closely observed, considering the visual examination as the simplest yet most effective test that can be applied to a transformer in operation, or in store. Status of each transformer, leakage condition and causes of the leakage, soil and water contamination from the leak, location and condition of the transformers and general and technical information of transformers like manufacture date and manufacturing country, were also noted. For this study, to understand the status of the transformers, they were broadly classified on the basis of year of manufacture, manufacturing country, power rating (capacity), their general condition (leakage, sound emission, soil and water body pollution or contamination) as well as the place where the transformers were located and mounted such as private compound, school compound, in or near temple, agricultural land, water body and roadside.

Results and Discussion

Distribution of Transformers

There were a total of 11 feeders under Kathmandu- North distribution centre. Name of available feeders and the total number of transformers within respective feeders along with consumer's number to each transformer is shown in Table 1. The average number of households connected per transformer of the Kathmandu North Distribution Centre was found uniform, which was to ensure the equal load pressure in all the transformers and to have lower risk of transformer failure (Bartley, 2003; Hartley and William, 2003). In this distribution centre there were 232 distribution transformers connected to 30545 household (NEA 2011). The average number of consumers connected per transformer in this distribution centre (129 household per transformer) was higher than overall average number of consumers connected per transformers in the Kathmandu valley (106 household per transformer) (NEA, 2011), resulting more load pressure on transformers of this distribution centers; this may be because of rapid urbanization in the study area.

Table 1: **Feeder wise distribution of the transformers**

S.N.	Name of Feeders	Number of Transformers	Household number	Households per transformer
1.	Tokha feeder	6	792	131
2.	Dharmasthali feeder	7	952	136
3.	GairhiDhara feeder	2	240	120
4.	Baluwatar feeder	7	980	140
5.	Samakhushi feeder	22	2948	134
6.	Gongabu feeder	36	4284	119
7.	Bansbari feeder	12	1764	147
8.	Golfutar feeder	5	690	138
9.	Budhanilkantha feeder	19	2394	126
10.	Om feeder	31	3782	122
11.	Lazimpat feeder	18	2502	139
Total		165	21328	129

Status of Transformers

The average working life of a transformer according to Basel Convention (1986) is 30 years; in the studied area, 9 transformers were more than 30 years old (Table 2), indicating that these over aged transformers could be considered as vulnerable ones. The production of PCBs was banned in 1990 after knowing its bioaccumulation and biomagnification characteristics (UNEP Chemicals, 1999); later in 2002 the Stockholm Convention focused on eliminating or reducing releases of 12 POPs including PCBs. One can therefore consider that dielectric fluid used in transformers manufactured after 1990 were PCBs free, however 31% of transformers of Kathmandu North distribution Center were found manufactured after 1990 but still consisted detectable concentration (>50 ppm) of PCBs in the oil (Table 2). The presence of PCBs in all these transformer oils might be possibly due to cross-contamination, either during retrofilling online transformers or during maintenance. Though Nepal Electricity Authority (NEA) had set the provision that the transformer oil should be PCBs free for purchase and import (NEA, 2011), at the same time there was also high possibility that the new transformers might also get PCBs contaminated as there was no provision and facility to examine and monitor the PCBs content in new transformers.

Table 2: Type of transformers on the basis of manufacturing year and their PCB concentration

Transformer Age Group	PCB concentration (in ppm)					Total number of transformers
	<50	50-100	100-150	150-200	>200	
1941-1950	3	-	-	-	-	3
1951-1960		-	-	-	-	0
1961-1970	3	-	-	-	-	3
1971-1980	3	-	-	-	-	3
1981-1990	23	-	2	-	-	25
1991-2000	36	-	-	1	-	37
2001-2010	33	1	-	-	-	34
2011and above	1	-	-	-	-	1
Na	5	-	-	-	-	5
Total	107	1	2	1	-	111

PCBs contamination was found in few transformers manufactured from France, Japan and Nepal, whereas no PCBs contamination was found in transformers manufactured from India, China and Korea (Table 3). This was due to the fact that these were either manufactured later than 1990, or were not subject to cross- contamination. Highest PCBs contamination was found in a transformer manufactured in France before 1990. As more than 50 percent of transformers originated from Nepalese manufacturers, PCBs contaminated fluid could be highly controlled by imposing restrictions on import of the PCBs contaminated transformers in future. NEA has already made a provision that any transformers oil it would produce, must be PCBs free (MOSTE 2014).

Table 3: Transformers manufacturing countries and PCBs concentrations detected

Manufacturing country	PCB concentration (in ppm)					Total number of Transformers
	<50	50-100	100-150	150-200	>200	
China	16	-	-	-	-	16
France	-	-	-	1	-	1
India	10	-	-	-	-	10
Japan	21	-	2	-	-	23
Korea	2	-	-	-	-	2
Nepal	56	1	-	-	-	57
Na	2	-	-	-	-	2
Total	107	1	2	1	-	111

Bartley (2003) found that 25kVA transformer failure in the USA was due to contamination. Less power rating transformers might not be good enough as a distribution transformer because of their high tendency to failure (Safe and Otto, 1984). In terms of PCBs contamination, lower capacity transformers with lower quality of dielectric oil often contained more PCBs because PCBs were mixed in such transformers to elevate the dielectric capacity of low quality oil (Safe and Otto, 1984); this might be the reason for PCBs contamination in 25, 50 and 100 kVA transformers in the present study but not in transformers ranging from 150 to 300 kVA (Table 4) even with the same manufacturing company.

Table 4: Transformers on the basis of power ratings and their PCBs concentration

Transformer Capacity (in kVA)	PCBs concentration (in ppm)					Total number of transformers
	<50	50-100	100-150	150-200	>200	
25	1	1	-	-	-	2
50	8	-	1	-	-	9
100	54	-	1	1	-	56
150	3	-	-	-	-	3
200	38	-	-	-	-	38
250	1	-	-	-	-	1
300	1	-	-	-	-	1
NA	1	-	-	-	-	1
Total	107	1	2	1	-	111

Location and Condition of Transformers

During the field study, 207 transformers were studied among which, 175 were on the roadside, 12 inside the private compounds, 6 inside the school compounds, 5 in the agricultural land, 6 in or near temple premises and 3 were in Distribution Centre- North (Table 5). Two meters of circumference from the pole, where transformers were placed, were considered as vulnerable of uncertain electrical phenomenon and also of PCBs contamination (UNEP, 1999), therefore all locations mentioned in Table 5 were thus found vulnerable of uncertain electrical phenomenon and also of PCBs contamination. Further, in any distribution transformer, uncertain hazards like insulation failure, overloading, fire/explosion, line surge, loose connection, oil leakage, etc. can take place at anytime. Therefore, all the transformers need continuous monitoring for any kind of uncertain phenomenon like leakage, holes, malfunctioning, sound emission, soil and water contamination.

Table 5: PCBs concentration in transformer at different locations

S.N.	Location	Level of PCBs Concentration (ppm)			Total Number of transformers
		0-20	20-50	Above 50	
1.	Roadside	62	26	3	91
2.	Private Compound	4	4	-	8
3.	School Compound	1	1	-	2
4.	Agricultural land	3	1	1	5
5.	Near Temple	2	-	-	2
6.	Basundhara Distribution Centre	-	3	-	3
Total		72	35	4	111

In this distribution centre leakage was seen in 7 transformers and the cause of leakage in all 7 transformers was found to be due to broken seals and gaskets; due to such leakage transformer oil was found contaminating the soil covering the surface area of 1.44 square meters (Table 6). The probability of PCBs contamination in this soil was very high and such soil would need to be sampled and examined for PCBs concentration and when contamination would be found above the guidelines ($\geq$ 50 ppm), it should be cleaned up to reduce the environmental impacts, because such PCBs may easily get into lakes and rivers and may bioaccumulate in fish and other wildlife. Ground water may also get PCBs contaminated through infiltration.

Nepal gets most of its rainfall in the Monsoon season (June – September), and during this season, PCBs washed away may make its way to the ambient environment, thereby increasing the risks of PCBs contamination in the nearby water body, soil and air. PCBs are not soluble in water, yet substantial quantities of PCBs contaminated water may flow from contaminated sites. For this ground water around the leaking transformer should be continuously monitored for PCBs contamination and surface water during the rain should be monitored and when found PCBs contaminated, should be contained and disposed off safely. Air may also get contaminated with PCBs during lightning strikes on PCBs contaminated transformers resulting its failure and the PCBs droplets in air can stay in the atmosphere for long period of time and can transport long distance before they get deposited over the earth surface (U.S. EPA, 2012). In this distribution center every year on an average 25 transformers gets failure and 7 transformers are leaking (Table 6) therefore there is probability of distribution centre atmosphere being contaminated with PCBs.

Table 6: Identification of leaking transformers

S. N.	Sample ID	Serial Number of transformer	Name of Feeder	Location (DCs -North)	Soil contamination by leak (in square meter)
1.	TdKN0094	S.13184	Gongabu feeder	Gongabu	0.48
2.	TdKN0120	TY1622	Tokha feeder	Tokha	only on transformer surface
3.	TdKN0131	GTS675114	Gongabu feeder	Mahadevtar, Gongabu	only on transformer surface
4.	TdKN0149	84-577	Budhanilkantha feeder	Chapali, Bhadrakali	only on transformer surface
5.	TdKN0161	1110321	Budhanilkantha feeder	Khaska, Bhadrakali	0.48
6.	TdKN0164	774116	Budhanilkantha feeder	ChapliChok	0.48
7.	TdKN0205	89-992	Samakushi feeder	Basundhara	only on transformer surface
Total					1.44

Four transformers of this distribution center located at residential area (Table 7) were found emitting a low frequency, tonal noise; this may be due to core vibration, winding vibration and transformer cooling system. Even though sound control engineering design can lower noise coming from transformers, it is recommended to examine the transformer for problem and solve it at the earliest or relocate the noisy transformer to areas away from residential areas.

Table 7: Noise emitting transformers

S.N.	Sample ID	Serial Number of transformer	Name of Feeder	Location
1.	TdKN0071	832020514	Om Feeder	DhumbaraiChok
2.	TdKN0145	84-578	Budhanilkantha feeder	Malung, Jhor
3.	TdKN0169	962026508	Budhanilkantha feeder	Budhanilkantha
4.	TdKN0189	810880A	Budhanilkantha feeder	Chunnikhel

PCBs Contamination

The instrument, L2000 DX Analyzer, work on the principle of chloride determination, but test cannot distinguish between chlorine of PCBs and any other chlorine-containing compounds, which may also be found in transformer oil (Finch, 1991). The negative results are thus indicators that PCBs are not present, but positive results only indicate that PCBs may be present along with other chlorine. Therefore, further verification of this result is required through other laboratory procedures using gas chromatograph.

Among 111 transformers, from which oil was collected during field visit, PCBs contamination (≥50 ppm) was found in 4 transformers (Table 8), and the volume of PCBs contaminated transformer oil in these transformers was 479.6 Kg; however all the transformers showed some level of PCBs. The Basel and Stockholm Conventions recommend phase-out of transformers contaminated with PCBs (≥50 ppm) under specific timelines rather than continued use and if possible such contaminated transformers should be replaced by new PCBs free transformers or refill the same transformers with a non PCB fluid like silicones, aliphatic hydrocarbons, poly-a-olefins, chlorinated benzenes and esters (UNEP, 2000).

Table 8: PCBs contaminated transformers

S. N.	Sample ID	Serial Number of transformer	Name of Feeder	Location (within Kathmandu-North)	Amount of PCBs contaminated transformer oil (in Kgs)
1.	TdKN0071	832020514	Om feeder	Dhumbarai Chok	141.9
2.	TdKN0114	612175-04	Gongabu feeder	Gongabu	170
3.	TdKN0173	2002.25.11. 5751	Budhanilkantha feeder	Shivapuri	64.5
4.	TdKN0190	2K0080	Budhanilkantha feeder	Gamcha, Chunnikhel	103.2
Total Volume of PCBs contaminated transformer oil (in Kgs)					479.6

The main problem associated with this PCBs contaminated transformers is to prevent cross contamination during retrofilling, replacement of leaking seals and repair of cracks and holes, clean-up of minor leaks or spills and timely addition of non contaminated transformer fluid (UNEP Chemicals, 1999).

If one goes through the ranges, 4% samples were PCBs contaminated and were posing risks to the human being and environment, as on use, transformers always shows some possibility of environmental exposure of their oil mechanically or accidently (Stockholm Convention, 2001). The identified PCBs contaminated transformer fluid must be isolated, safely stored and dispose off as soon as possible. Each time during purchase of new transformers and transformer oil, the PCBs concentration must be examined and monitored for any illegal import of PCBs contaminated oil. NEA should also monitor for any cross contamination at workshops during maintenance of transformers by testing the transformer oil brought for maintenance. By this process PCBs contaminated oil, can be removed from this distribution centre.

Once in the environment, PCBs do not readily break down and therefore may remain for long periods of time cycling between air, water, and soil. PCBs can be carried long distances and have been found in snow and sea water in areas far away from where they were released into the environment (USEPA, 2012). As a consequence, PCBs are found all over the world. They are also taken up into the bodies of small organisms and fish. As a result, people who ingest fish may be exposed to PCBs that have bioaccumulated in the fish. PCBs are suspected to cause cancer, as well as a variety of other adverse health impacts on the immune system, reproductive system, nervous system, and endocrine system (USEPA, 2012).

According to UNEP Chemicals (1999) destruction of PCBs molecules present in the transformer oil can be done through physical, microbial and chemical methods, however incineration (physical method), in which PCBs contaminated transformer oil is burnt at temperature at or above 1200°C for at least 2 seconds and dechlorination (chemical method), in which chlorine of PCBs are substituted by polyethylene glycols to produce aryl polyglycols, which are insoluble in the oil and precipitate out are common and environmentally accepted methods worldwide.

Conclusion

Distribution of transformers in different distribution centers of the Kathmandu valley was not at the same proportion. However, in the Distribution Centre- north it was quite uniform. Seven transformers were found leaking and the cause of leakage was due to broken seals and gaskets. Around 1.44 square meters of soil surface was found contaminated by transformer oil. Four transformers of this distribution center located at residential area were found emitting a low frequency, tonal noise. Among 111 PCBs analyzed DTs, 4 transformers were found to be PCBs contaminated at ≥50 ppm and thus identified as PCBs contaminated according to UNEP (1999). They were manufactured before 1990s. The total volume of PCBs contaminated (≥50 ppm) transformer fluid in these transformers was 479.6 Kg still all the transformers showed some level of PCBs in them. Proper handling of PCB contaminated transformers, continuous monitor for any leaks, holes, malfunctions and timely maintenance of any defect would be a reasonable approach to contain and reduce cross contamination among transformers and also to avoid the environmental contamination of PCBs.

Acknowledgment

The authors would like to thank the staff of College of Applied Sciences-Nepal for their support, Ministry of Science, Technology and Environment (MOSTE) for the laboratory support, Nepal Electricity Authority (NEA) for the support during field works in carrying out the research work. Special thank goes to Laxman K.C., Annu Rajbhandari and Netra Mani Kattel for their valuable suggestions and inspiration to carry out the work.

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