# STUDY OF ELECTRICAL EQUIPMENT AS PCBs EMISSION SOURCE ON THE TERRITORY OF BELARUS

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**Abstract**

In the paper first results of electrical equipment as PCBs source identification and estimation on the territory of Belarus are discussed. The study includes identification of electrical equipment with PCBs, estimation of PCBs fluids volumes, inventory of equipment with PCBs, evaluation of PCBs loses and emission, sampling and analysis of PCBs content in soils near electrical installations and storage places. Main types of PCBs fluids, diagnostic features of electrical equipment with PCBs are described. The peculiarity of PCBs leakage from capacitors and transformers are shown. Results of balance (production-consumption) approach for PCBs estimation are described.

According to estimates, in Belarus can be approximately 500 tonnes of PCB in transformers and 500 tonnes of PCB in capacitors now; total annual release of PCBs makes up about 1 tonne; annual PCB emission – about 500 kg.

On the whole it is shown that PCBs-containing equipment is a serious problem which should be solved in view of international agreements recently adopted.

## Introduction

Polychlorinated biphenyls (PCBs) like DDT belongs to the first historically recognised persistent organic pollutants (POPs). Many of the same chemical and physical properties that had made them usefull in industry, also made them one of the most widespread contaminants in the environment.

Contamination of the environment by PCBs was identified as a problem in the late 1960s (1). Lately it was found that PCBs generally present ewerywhere, in various environment media and in human beings. This is due to their persistence possibility of distribution over large distances, their high potential for bioaccumulation and biomagnification.

During the 1970s and 1980s actions were taken by countries to stop PCBs production and the manufacture of equipment containing PCBs. However, while measures have been taken to address PCBs production, up to two-thirds of the 1.2 million tons ever produced are either still in use or in storage (2).

Polychlorinated biphenyls had and partially have various applications - in closed systems (such as dielectric liquids in capacitors and transformers, in hydraulic and cooling equipment, cables), in production of dyes, plastifisers (so-called open application).

Electrical equipment was the most important user of PCBs and, respectively, a source of secondary environment pollution by PCBs. For example, in the USA until 1971 61% of the PCBs were used in dielectric fluids, after 1971 – 100% (3). According to the data (2, 4), in Germany 55.5% of PCBs were used in dielectric fluids, in Japan - 66%. About 75% of the PCBs manufactured in the formed USSR were used in dielectric fluids (5).

Recent estimates of the European emissions (6) indicate that as much as 94% of PCB emissions come from this source. The bulk of emission of PCB results from direct leakage from damaged electrical equipment.

## Methods

The purpose of this study - revealing and preliminary assessment of PCBs releases and emissions from electrical equipment over the territory of Belarus. Up to the moment there were no data about PCBs in Belarus, including their volumes in equipment, storage, contents in emissions and environment components.

The procedure of investigation included the following stages:
- identification of equipment types with PCBs;
- estimation of PCBs volume in electrical equipment;
- description (revealing) of PCBs releases conditions from electrical equipment and estimation of levels of PCBs releases;
- preparation of emission factors of PCBs;
- calculation of PCBs emission.

**Results**

***Electrical equipment with PCBs identification***

Power capacitors and transformers are the main types of PCBs-containing equipment in Belarus (as in countries of the Former USSR). PCBs also can be used in mining and hydraulic equipment, some other applications, but there are no data of such usage of PCBs in Belarus.

In the USSR during 1959-90 for the production of capacitors 90 thous. tonnes of PCBs was consumed; 57 thous. tonnes of Sovtol-10 have been consumed for the transformer production since 1939 (7).

Capacitors used for increase of the power factor have the widest application with the share up to 70% of total capacitor output (8). High frequency capacitors took the second place in the capacitors output.

From the whole set of capacitors produced, it is essential to single out those filled with PCB-based fluid. The type designations for identification PCBs-containing capacitors may be used. According to the technical regulations and standards, the second letter stands for dielectric type in the capacitor type designation, e.g. S- synthetic liquids impregnation.

The following capacitors types with PCBs produced in the USSR are singled out: KS, KSK, IS, ESV, ESVP, ESVK, ESB, KSP, GST, RST (8, 9, 10). They were produced at two plants: Serpukhov Capacitor Plant (Russia) and Ust-Kamenogorsk Capacitor Plant (Kazakhstan). Small capacitors with PCBs for lighting technology and air-conditioner were produced at Leninakan electrotechnical plant (Armenia) (they are not considered in the current study). As impregnation fluids mainly trichlorobiphenyls, to a less extent Sovol, Pyralene 3010, 1460, Clophen A-30 were used.

Capacitors of European countries manufacture are also used in Belarus. It has been pointed out, that such PCB-filled capacitors as LKC, LA-Z, LOGE, BR, etc. type made by ISOCOND company (Leipzig and Annaberg) are used at industrial enterprises.

Dielectrics amount in capacitors varies depending on its type from 2.7 kg (PSK type capacitors) to 22-24 kg (KS2, KSP capacitor types). Capacitors that have the widest application have the following average fluid volume: KS1, KSK1 - 10 kg; KS2, KSK2 - 19 kg; IS - 18 kg; ESV - 8.5 kg. According to the data (3) the large high voltage capacitors in the USA typically weigh 54 kg of which 11 kg are PCBs.

Transformers are used for electric power transformation in power transmission lines and in power energy receipt and use units. Transformers filled with transformer oil are most widely used now in Belarus. In some cases noncombustible synthetic fluids like Sovtol-10 (rarely Hexol and some other fluids) are used. The physical size and shape of transformers vary greatly, from not much bigger than a pea up to size of a small house (11). In the list of the main transformer types with PCBs are TNZ and TNZP (made on Chirchik transformer plant). Among electrical equipment produced at Uralelectrotyazhmash Amalgamation TNPU, TNP, TNRU, TNZRU are known, but their production was stoped in 1974.

Volume of Sovtol-10 in transformers was defined using the data obtained at enterprises: TNZ -40/10 - 205 kg, TNP-800/10 - 2.75 t, TNP -1600/10 - 3.3 t, TNZ-2500/10 - 4.12 t etc.

Main capacitors and transformers users are power transmission lines (power substations), railway traffic (traction substations), sea transport and also industrial enterprises.

***Estimation of PCBs volume in electrical equipment***

Data on total PCBs volumes in electrical equipment are necessary for PCBs releases and emission calculation. At present PCBs volumes evaluations have been conducted for some countries: USA, Czech Republic, Japan, Germany, Great Britain etc. (12). Recently results of the AMAP PCBs inventory in Russia were issued (7).

During our investigation it was stated, that at present in Belarus annual electrical equipment inventory takes place only in power industry (disregarding types of fluids); on the basis of data available, capacitor type and its brand, one can single out only those with synthetic chlorine-containing liquids. At industrial enterprises there is no account of electrical equipment by types.

We have conducted a partial capacitors and transformers inventory for enterprises of Power Industry, Railway Transport and at some large Belarusian industrial enterprises. The inventory was made

separately for transormers and capacitors with the indication of their type, dielectric type, equipment number, year of manufacture, producer. Electrical equipment that was in operation, in reserve and also damaged one was taken into account.
On the basis of data obtained one can say, that the main capacitor amount now in operation is represented by capacitors with PCBs. A considerable equipment part was manufactured before 1980, i.e. practically it is out of operation.
A selective inventory of electrical equipment with PCBs was conducted using feedbacking of the largest enterprises. Not all questioned enterprises reply; others showed number of capacitors and transformers and their type. Using this data PCBs and volumes of PCBs by type total volume of PCBs was calculated. On the whole 63.4 t has been revealed by the present in transformers and 151.1 t PCBs in capacitors.
It was indicated, that part of PCB-containing equipment was out of operation due to its physical wear, case damage or other reasons. By the results of selective inventory more than 900 capacitors and 10 transformers out of operation were revealed.
Was used also another and rather effective method of PCBs quantity estimation – balance approach on the basis of PCB-containing equipment production data. Using data on total production of PCB in the USSR, their consumption by producers of electrical eqipment, electrical equipment distribution among economy sectors, duration of the life-cycle of equipment and comparative figures on industrial structure of the FSU countries it was obtained, that in Belarus can be approximately 500 tonnes of PCBs in transformers and 500 tonnes of PCBs in capacitors now.

***PCBs release study***

Capacitors are closed appliances where the PCBs are in totally sealed containers. PCBs environment release is impossible in the process of capacitor operation. The possibility of capacitor no-failure operation during 20-year period makes up about 0.9, electrical equipment operating time - 20-25 years. Dielectrics replacement in capacitors does not take place; liquids operating time coincide with the equipment one.
The main PCB releases into the environment are the result of spills from electrical equipment in fault condition. The main reasons of capacitor fault are disruption (sometimes with metallic case depressurization), equipment wear, case corrosion. The probability of case damage is decrease from paper capacitors (KS type) to film-type ones (KSK type) and further to film: for the first paper decomposition by electric arc is characterized by a strong gas formation, swelling and case damage often with inflammation (paper is a wick to feed a combustion site with impregnation liquid). At arc film-type capacitor disruption the film begins to melt and dissolve, the arc dies out, the case does not swell and not explode (13).
At capacitor casing failing and cracks formation in the casing bottom practically all free liquid spills. In case of casing depressurization in the top, significant spills are connected more often with disassembling non-observance of damaged equipment and its storage.
At present in Belarus a considerable part of capacitors is not used. Due to the general fall in electric power consumption network reactive capacity has increased. Capacitor units switching-off for a long time (at some substations they have not worked for 2-3 years already) the danger of quick metallic casing rapture and liquid spills increases.
Transformer operation time is 40 years. Tank with dielectric fluid (Sovtol-10) is hermetically closed, but in the lower part of tank there is a tap for emergency discharge of fluid. In the process of operation some leakages through this tap are possible. For transformers replacement of cooling liquid is provided, however, in practice there is only a regular replacement of transformer oil. According to the supplement of 01.06.86. to Standard 16555-75, transformers with Sovtol-10 should be used without major repairs (and probably without liquid replacement). For work with synthetic chlorine-containing liquids specially equipped areas, reservoirs, etc are necessary. Therefore, often at out-of-operation liquid of Sovtol-10 type the transformer cannot be longer used (at least such situation is characteristic for Belarus).

***PCBs releases and emission factors estimation***

Capacitors

Emission factors calculation was done for enterprises where experimental studies took place, including examination of capacitor units, storage places of damaged equipment, consultations with experts.
Initial data: PCBs volumes in damaged equipment and that in operation; share of free fluid in capacitor; capacitor share with failed (damaged) casing; equipment operation time.
PCBs emission factors calculation is demonstrated on the example of three objects.

Object 1 - industrial enterprise. During 24 years of capacitor unit operation 78 capacitors fell out, i.e. about 62% of their total amount. Hence, 2.4% of PCBs volume became out of operation annually with the damaged equipment, part of which released into the environment. The majority of capacitors fell out without casing failure, and since they are stored in closed premises (brick building) there haven not been any gross equipment spills recently. At the same time, in some capacitors the casing was depressurized deliberately (copper terminals were removed); the share of such capacitors is about 10%. For such capacitors PCBs spills and evaporation are possible. Emission factor makes up 0.14%.

Object 2 - traction substation. It was introduced into operation in 1982. About 20 capacitors out of the total amount (78), turned to be damaged for 16 years of operation. According to the calculation, 1.6% of total fluid amount was put out of operation annually with damaged equipment. Taking into account the share of free fluid, about 0.96% of total fluid amount could have spilled into the environment. At present practically all damaged capacitors have been depressurized, some have a casing that is completely failed, i.e. about 50% of capacitors spill. Possible PCB spills can be roughly estimated as 0.43% per year.

Object 3 – electric power substation. During 18 years of capacitor operation 210 units fell out (7.6% of their total amount). Hence, 0.48% PCB volume with damaged equipment was put out of operation annually. Approximately 1/4 of equipment was put out of operation with failed casing. Thus, PCBs share releasing into the environment makes up 0.07% of total fluid amount in capacitors.

The share of PCBs spills with damaged equipment for other objects varies within 0.10-0.25%.

Transformers

As case study objects transformers of three Minsk plants have been considered. All transformers with Sovtol-10 are installed in special premises. Their condition is controlled; when signs of leakages are detected specials measures for liquidation are undertaken. It was revealed only one damaged transformer. Estimation of amount of Sovtol-10 flew out is very hard; on enterprises specialists opinion it can vary from 0.1 to 10 kg per year.

As a whole our investigations allowed to estimate average leakage (releases) of PCBs from such equipment. On our estimates they amount 0.3 kg/t for transformers and 2 kg/t for capacitors per year.

It is known that not all PCBs flown out volatilizes. The volatilization process is very complicated and depends upon many local conditions (3). It was determined that on the whole volatilization rate decreases with the growth of chlorination degree. For this reason Trichlorodiphenyl which flew out from capacitors volatilizes more rapidly than Sovtol-10 which run out of transformers. Taking into account literature data and peculiarities of equipment operation we assume that 40% of leaked Trichlorodiphenyl and 20% of Sovtol-10 (pentachlorobiphenyl) volatilize. Coefficients applied are of great uncertainty but in modern situation can hardly be evaluated more precisely. For instance, in Germany coefficient of 10% was applied for PCBs emission from spills estimation (4).

Mentioned coefficients were used for the estimation of PCB emission factors (Table 1). These figures are on the whole in good accordance with (scarce) literature data. Thus, according to (14), PCB spills for capacitors makes up 0.16% of total PCB amount in capacitors; for transformers the spills share is 0.006%. On the basis of data (15), the spills from capacitors and transformers are considerably higher and makes up 0.42% and 0.03% respectively.

Table 1: Leaks (releases) and emission factors of PCBs from electrical equipment, kg/t

| Equipment | Leaks (releases) | Emission | Country or region | Reference |
|---|---|---|---|---|
| Transformers | 0.06 | - | Europe | (14) |
| | 0.3 | - | North America | (3) |
| | 0.3 | 0.06 | CIS countries | (5) |
| | 8.82 | | Russia | (7) |
| Capacitors | 1.6 | - | Europe | (14) |
| | 4.2 | - | North America | (3) |
| | 2.0 | 0.8 | CIS countries | (5) |
| | 0 | | Russia | (7) |

**PCBs releases and emission estimates**

According to estimates, total annual release of PCBs in Belarus makes up 1140 kg; annual PCBs emission – 426 kg.

Comparison of PCBs emission in Belarus by different estimates are given in Table 2.

Table 2: Comparison of PCBs annual emission in Belarus by different estimates, kg/year

| Compound | Estimate by (6) | Estimate by (16) | Current estimates |
|---|---|---|---|
| PCBs | 600 | 566 | 426 |

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**References**
(1) Jensen S. Report of a New Chemical Hazard. New Scientist. V.32, (1966)
(2) WHO. Environmental Health Criteria 140: Polychlorinated Biphenyls and Terphenyls (second edition), Geneva, Switzerland, (1993)
(3) Locating and Estimating Air Emissions from Sources of Polychlorinated Biphenyls (PCB). US EPA-450/4-84-007n., (May, 1987)
(4) Neumeir G. Toxicology and Health Impact of PCBs. Proceedings of the Subregional Awareness Raising Workshop on Persistent Organic Pollutants (POPs). Kranjska Gora, Slovenia, (11-14 May 1998)
(5) Kakareka S, Kukharchyk T, Khomich V. et. al. Study for Evaluation of Emission Factors of Selected POPs from Main Activities of the CIS Countries. Belarusian contribution to EMEP Annual report 1999. MSC-E, Minsk – Moscow, (2000)
(6) Berdowski J.J.M., Baas J, Bloos JP.J , Visschedijk A.J.H., Zandveld P.Y.J. The European Atmospheric Emission Inventory for Heavy Metals and Persistent Organic Pollutants. Umweltforschungsplan des Bundesministers fur Umwelt, Naturschutz und Reaktorsicherheit. Luftreinhaltung. Forschungbericht 104 02 672/03. TNO, Apeldoorn, The Netherlands, (1997)
(7) PCB in the Russian Federation: Inventory and Proposals for Priority Remedial Actions. AMAP Report. ISBN 82-7971-008-6. Arctic Monitoring and Assessment Programme (AMAP), Oslo. Published by: Centre For International Projects (CIP), Moscow, (2000)
(8) Gulevich A.I, Kireev A.P. Manufacture of Power Capacitors. Fourth edition. Moscow, (1981) (In Russian)
(9) Power Electrical Capacitors. Moscow: Energy, (1975) (In Russian)
(10) Reference Book for Electrotechnical Materials. / Ed. by J.V.Koritski et al V.1. Second edition. Moskow: Energy, (1974) (In Russian)
(11) Guidelines for the Identification of PCBs and Materials Containing PCBs. First Issue. UNEP Chemical, (August, 1999)
(12) Information–Methodological Materials on Problems of Prevention of the Environment Pollution by Polychlorodi(bi)phenyls. Ekaterinburg, (1997) (In Russian)
(13) Varschavski D.S. Power Capacitors/ Results of Science and Technology. Volume16. Moskow, (1991) (In Russian)
(14) Technical Paper to the OSPARCOM-HELCOM-UNECE Emission Inventory, TNO-report, TNO-MEP-R95/247, (1995)
(15) Holoubek I., Caslavsky J., Nondek L. et al. Compilation of Emission Fctors for Persistent Organic Pollutants. A Case Study of Emission Estimates in the Czech and Slovak Republics, (1993)
(16) Pacyna J.M. et al. Technical Report. Appendix 1. To the Executive Final Summary Report. Environmental Cycling of Selected Persistent Organic Pollutants (POPs) in the Baltic Region (POPCYCLING-Baltic project) Contract No ENV4-CT96-0214, (1999)

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