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EFFECTIVENESS OF AGRICULTURAL TRACTORS CABS FOR PROTECTION AGAINST HAZARDOUS SUBSTANCES IN ACCORDANCE WITH EN 15695 PART 1

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ABSTRACT Tractors and self-propelled machine operators can be exposed to hazardous substances such as plant protection products, fertilizers and other toxic materials generated during soil tillage and harvesting. Cabs fitted on these machines can provide protection against these substances and can be used to reduce operator exposure to air contaminants. Recently available Standard EN 15695-1:2009 provides 2 test procedures to asses the protection cabs are able to assure protection to operators with regards to hazardous substances. The first method consists in measuring the cab tightness using an artificial generated aerosol. A number of studies have been conducted to develop this method, references supporting these results are available. The second method, called “blind filter test” in the Standard, consists in blocking the active filter area and measuring the air leakage through the filter seat. Little informaiton is available about this second method. Thus a blind filter test has been performed on a cab fitted on an agricultural tractor to asses the effectiveness of the method in measuring the air tightness of the enclosure. The test has been performed on a 75 kW, four wheel drive orchard tractor fitted with a cab equipped with carbon filter filtration system. Different combinations adjustment of the engine and fan speeds, and air recycling and aperture for remote operations have been examined. During the investigation improper assembly of the filter housing was detected. Therefore the investigation confirms that small cracks due to faults in filter assembly are the major source of penetration of hazardous materials into the cab enclosure. In accordance with the obtained result of the study the blind filter test seems to be an appropriate method to verify the protection against hazardous materials of fitted cabs fitted on agricultural machines. Furthermore the test is simple, does not require special facilities or expensive instrumentation, or skilled personnel. Nevertheless additional tests are necessary on a widder range of tractor cabs to increase existing knowledge in regards to the alternative procedure to asses the tightness of cabs.

Keywords: Tractor, Cab, Filtration, Dust, Aerosol, Pesticide.

INTRODUCTION Agricultural workers are exposed to pesticides while handling and spraying crops with sprayers, trailed or carried by tractors, or with self-propelled spraying machines. The spray application gives an aerosol. Pesticides are less commonly distributed under vapour and gas forms.

Crystalline silica and airborne pathogens (bacteria, fungi, endotoxin) are other additional source of exposure to hazard for agricultural workers. These toxic materials are components of the dust occurring for example during grain harvest, soil tillage operations, and generated by activities with livestock (Goering et al. 2003, Chisolm et al. 1992).

All the above mentioned agricultural activities are carried out using machines having a driving station. Drivers are required to wear appropriate personal protection equipment (PPE), such as protective garment and gloves, hood and visor, to prevent skin contamination, and respiratory protection equipment (RPE), for example headdress (with face protection) and half-mask with filters, to avoid respiratory exposure to hazardous substances.

Thorpe (2003) indicates the provision of a cab filtration is a better approach when the filtration system is of a type able to deal with the hazard presented. Furthermore greater use of pesticides in agriculture and forestry and increased human protection requirements suggest the importance of a tractor cab as a protective device as stated by Goering (2003). As pointed out by Hall (2002) for respiratory protection a cab must provide the protection that is equivalent to the RPE specified for the toxic substances.

Figure 1 schematically describes a typical cab filtration system.

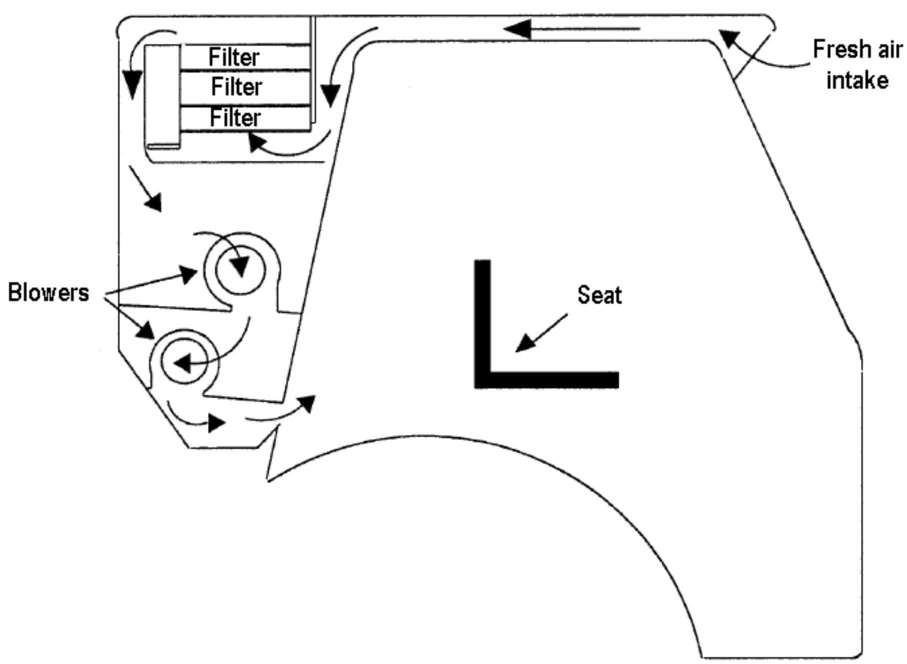

Figure 1. Schematic description of a typical cab filtration system (Adapted from Heitbrink et al., 1998)

Generally, the air cleaning system implemented on cabs on agricultural machinery comprises a single filter, or a set of filters, depending if it is designed to stop dust particles, aerosols, gasses or vapour. Some ventilation systems enable recirculation of a part of the air of the cab to filters after its reintroduction. Purified air into the cab is supplied by a motor blower. The internal environment of the cab is slight pressurized.

The air flows out of the pressurized cab through leaks and/or a vent port. A vent port is designed to allow air to leave the cab at a location that is shielded from the effects of the wind. However cab filtration systems have some air leakage due to the need for electrical and mechanical connections between the cab and the rest of the equipment, defects in welding sites, imperfections in caulking sealing, improper filter sealing, imperfections in gasket materials, deterioration of gaskets and other sealants, and so on (Moyer et al., 2005).

Agricultural vehicle cab filtration systems may use different types of filters: paper filters, glass fibre filters, textile fibre filters, non electrically charged filters, non-fibrous filters, and carbon activated filters, whose main characteristics has been described by Thorpe (1997).

A number of research studies have been conducted to develop test methods for establishing cab performance in laboratory or in the field (Bémer et al. 2009, Organiscak and Cecala 2009, Bémer et al. 2005, Moyer et al. 2005, Heitbrink et al. 2003, Thorpe et al. 2003, Hall et al. 2002, Heitbrink et al. 1998, Thorpe et al. 1997). These studies determined the efficiency of cabs filtration system using artificial generated aerosol, and filtration cab efficiency is defined as the ratio between eternal and internal aerosol concentration difference and the external concentration.

Cecala (2005), in accordance with results of researches, identify the two key components necessary for an enclosed cab to be effective from a toxic material control point of view: effective filtration and cab integrity. Thus effective filtration depends on filter performance while cab integrity is in relation with leaks. Hall (2002) and Heitbrink (2003) agree on the fact that penetration through the filter media is not a major source of leakage into the cab.

The most critical leaks are the leak sites around the filters due to filter sealing problems (faulty gaskets, bowed flanges, etc.) causing air contaminants to bypass the filters. Also leaks from the filter housing to the cab interior, in negative static pressure, are critical. Studies have not found significant leakage into the cabs through normal air exit routes.

Results of investigation concluded that leakage is the main aspect affecting isolation of cabs from hazardous material. High leakages tend to be associated with what appears to be poor design. So it is necessary that filter-sealing systems be well-designed, and that good fitting procedures are employed to assure effective protection from dangerous substances.

As results of investigations conducted it can be assumed that tractors and self-propelled machines cabs can be effective for protection against different toxic materials depending on the seals and filters used.

Agricultural and forestry tractors sold in European Union are submitted to type-approval process under the frame European Directive 2003/37/EC regulating aspects for road safety, safety at work, and environmental protection. Protection against hazardous substances, as other risks, is not taken into account by this Directive.

Risks to safety and health arising, or likely to arise, from the effect of chemicals agents that are present at the work place or as a result of any work activity involving chemical agents are dealt by the EC Directive 98/24/EC. This Directive state that risks to the health and safety of workers at work involving hazardous chemicals agents shall be eliminated or reduced to a minimum by the design and organization of system of work at the work place. These provisions are included in the Directive 2006/42/EC on machinery (the Machinery Directive) that requests that machines must be designed and constructed in such a way that risks of inhalation, ingestion, contact with the skin, eyes and mucous membranes and penetration through the skin of hazardous materials and substances which it produces can be avoided. Since in agricultural activities is not possible to place the hazardous environment inside a container in these operation the cab became an engineering control and act as a reverse container; therefore the cab has to be compliant with the safety requirements.

Standard EN 15695-1:2009, prepared under a mandate given to CEN by the European Commission, provides a means of conforming to the essential safety requirements of the Machinery Directive. Furthermore compliance with the normative clauses of this standard confers a presumption of conformity with the relevant essential requirements with respect to the emissions of hazardous materials and substances.

The purpose of the standard is to limit the exposure of the operator (driver) to hazardous substances when applying plant protection products (PPP) and liquid fertilisers. The standard specifies different categories of cabs of agricultural and forestry tractors and self-propelled sprayers and the relevant requirements and test procedures in order to limit the exposure of the operator (driver) to hazardous substances when inside the cab. Moreover the standard identifies the information to be provided by the tractor or self-propelled machinery manufacturer to the users.

Two methods to measure the tightness of the air delivery and filtration system are included in the Standard. First method consists in measuring the overall cab separation efficiency by exposing the cab in a closed room to a fine artificial aerosol. The second method consists in blocking the active filter area and measure the leakage flow through the filter seat. The Standard calls this alternative method “blind filter test”. This method is reported by Hinz (2008) as simpler and already used for testing filters for automotive use.

So far no references are available about the blind filter test. Thus this test has been performed on cab fitted on an agricultural tractor in order to verify the effectiveness of the technique, to acquire knowledge on its execution, and to report results of the investigation.

MATERIAL AND METHOD Tests has been performed on a 75 kW, four wheel drive orchard tractor equipped with a cab directly fitted on the tractor at the tractor assembly plant.

The tractor manufacturer claimed the cab able to provide protection to the driver against dust and aerosol. Thus, in accordance with protection specification of EN 15695-1:2009 the cab could be included into category 3. The test has been carried out before the entry into force of the Directive 2006/42/EC, so the manufacturer at that time had not to be compliant with provisions stated by this directive. Test has been performed in agreement with the manufacturer in order to verify the fulfilment of the requirement of the EN 15695-1:2009.

The tractor has been supplied by the manufacturer, randomly taken from the series production. The filtration system was made up of two air inlets and filters on the top sides of the cab. The filters housings were made from holes in the plastic material of the roof reinforced with metal frames. The filters were carbon filters without any marking with regards of the filtration standard they fulfil.

Test was carried out on in accordance with Annexe B "Determination of leakages of air delivery and filtration system installed in the cab" of the EN 15695-1:2009 which purpose is to asses the relative leakage related to the nominal air flow through the filter.

In accordance with the standard the air inlets of the delivery and filtration system of the cab have been covered with 2 test hoods, and the air filtration system has been operated first with the filters delivered with the tractor and later with filters with covered filters surface to prevent the air flow through the filters material.

In both cases the procedure requires the air velocity to be measured at the inlet side of the test hood, as schematically described in figure 2. 2 test hoods have been connected with a single circular duct having constant diameter where the air velocity has been measured.

The average air velocity through the circular duct was measured by an hot-wire anemoter on 12 points at on 2 cross-section of the pipe in accordance with Log-Tchebycheff method. Points of measure were on straight and horizontal segment of the pipe, faraway from curves affecting the steadiness of measures.

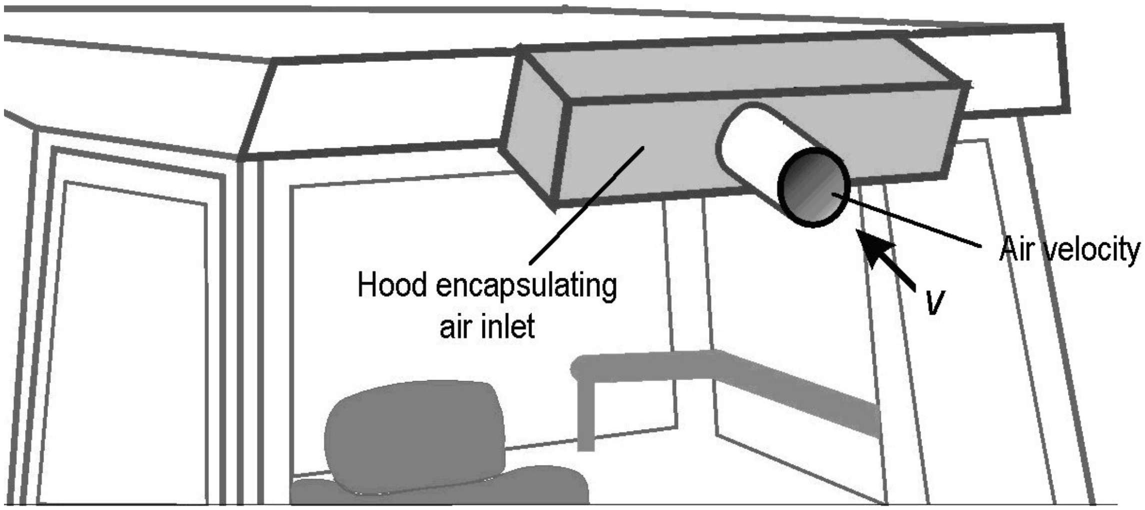

Figure 2. Example of blocked filter unit with hood encapsulating nominal air inlet and array to measure air flow velocity (Adapted from Hinz, 2008)

In accordance with the Standard the relative leakage (L_R) is determined by the following relationship:

$$L_R = \frac{Q_2}{Q_1} \qquad (1)$$

Where:
Q_1 is the air velocity with the filter(s)
Q_2 is the flow with the filter(s) with covered filters surface

The requirements of tightness of the air delivery and filtration system are considering fulfilled when L_R<2%

Cab ventilation system of the tested tractor was equipped of 3 speeds fan and recycling system. Inside air is recycled for air conditioning purpose only, so it does not goes through the filters. The cab was equipped with aperture for the remote operation of mounted or trailed equipments. Tractor rated engine speed was 2200 rpm.

Tests to assess the tightness of air delivery and filtration system have been carried out under the different combinations of the adjustment of the following conditions:

- **Air recycling:** open or closed
- **Fan sped**: 3 speeds
- **Aperture for remote operation**: closed or with 2 cables 12 mm diameter each for simulating operation condition
- **Engine speed**: minimum or rated

RESULTS Measures of air velocity under the different combinations of adjustments of the air delivery and filtration system was carried out first with filters normally in place.

Then, a second set of measures was conducted in the same condition as before but with filters with the surface of filtration hermetically covered and sealed. Air velocity during this second set of tests was unexpectedly high. Relative leakage calculated in accordance with equation (1) with these two set of measures was largely above the limit required by the Standard.

Visual examination of filters and filters holder assemblies into the housings led to identification of incorrect mounting of the gaskets between the filters plastic housing on the plastic roof and the metal frames against which the filters gaskets are pressed. This improper assembly allowed air to flow through cracks between plastic and metal, bypassing the filters.

The gaskets between plastic roof housings and metal frames have been removed and replaced with new ones properly placed by the tractor manufacturer staff.

Measures of air velocity with filters with and without surface of filtration covered have been conducted again. The relative leakages computed in accordance with equation (1) are summarized in table 1 and 2.

Table 1. Relative leakages with aperture for remote operation closed.

Fan speed	Air recycling closed		Air recycling open	
	Engine min	Engine rated	Engine min	Engine rated
	%	%	%	%
1	2.0	1.3	2.0	3.3
2	2.6	2.8	1.4	1.3
3	1.7	2.0	1.1	1.2

Table 2. Relative leakages with aperture for remote operation with 2 cables for simulating operation condition.

Fan speed	Air recycling closed		Air recycling open	
	Engine min	Engine rated	Engine min	Engine rated
	%	%	%	%
1	1.5	2.7	2.4	2.8
2	1.9	2.4	1.8	2.6
3	2.3	2.1	1.6	1.9

The relative leakages calculated in accordance with the blind filter test are below or close to the limit stated by the standard to consider a cab satisfying the requisite of tightness of the cab.

In 11 case of the 24 conditions studied the relative leakage is lower then the 2% stated as limit to consider the cab having the required tightness.

Relative leakages lower than 2% appear to be randomly distributed among all tested conditions. Probably there is an interaction among the different adjustments of the fan and engine speed, and the opening of the inside air recycling and of the aperture of remote operation. Additional experiences are required to better understand the relationship and the effect of these conditions on the expected results of the test.

The test was only for evaluating the method of assessment of the tightness of the cab and not addressed to measure the protection of the specific tested cab against hazardous substances. Nevertheless, in accordance with results of the tests, we could say that this specific model of cab fitted on the tractor could guarantee protection against dangerous material when the tractor is used for spraying operation only when the fan is at the higher speed whichever the other conditions affecting the tightness of the cab are. This specification should be reported on the operation manual of the tractor.

CONCLUSION The objective of the study was to report a first experience on the blind filter test, not to directly evaluate the protection performance of the specific cab on which the study has been carried out.

The blind filter test to assess the tightness of a tractor cab carried out on a cab in accordance with EN 15695-1 gave satisfactory results. This test method seem to be a convincing alternative to artificial generated aerosol concentration method. Further more it is simpler, do no required special facilities, expensive instrumentation, and particularly skilled personnel

However, additional tests on differently designed cabs are necessary to achieve the same knowledge on this testing methodology at the present time available for alternative methods, such as artificial generated aerosol, to asses the confinement of the enclosure of a cab against hazardous material.

The investigation showed that the slightest defect in filter assembly lead to detection of significant leakage during the blind filter test. This confirms that improper seat of the filter into the filter housing, as other fault in filter assembly, gives important degradation in protection performances of cabs against hazardous materials that penetrate into the enclosure through tiny crack around the filters.

The failing of the first set of measures of the relative leakage during the investigation due to defective assembly of the filter system on the specimen of the cab tested confirms, as already pointed out by Heitbrink (2003), that manufacturers should implement a quality control program to be sure that “every” cab provides requested protection performances against hazardous material. Appropriate service and maintenance programme of air delivery and filtration system in accordance with instructions provide by the operator’s manual shall assure that the protection performance does not decline during the time with respect the original protection level.

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