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Final Report
Verifying the effectiveness of Solvent RMMs

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ABBREVIATIONS

AUC	Area under the curve (=a measure for the total amount of ethanol measured at the sampling probe within a given time window of a simulation)
CHESAR	CHEmical Safety Assessment and Reporting tool
CSA	Chemical safety assessment
CSR	Chemical safety report
ECEL	Exposure Control Efficacy Library
ECETOC	European Centre for Ecotoxicology and Toxicology of Chemicals
ECHA	European Chemicals Agency
EEC	Extrapolated ethanol concentration
ES	Exposure scenario
ESIG	European Solvents Industry Group
ESVOC	European solvents volatile organic compounds group
EtOH	Ethanol
LEV	Local exhaust ventilation
NA	Not applicable
NoE	No observable increase in ethanol concentration in the room
REACh	Registration, Evaluation, Authorisation and Restriction of Chemicals
RMM(s)	Risk management measure(s)
TRA	Targeted Risk Assessment Tool

1 SUMMARY

This report describes work that was performed to evaluate the exposure reduction efficiency associated with different risk management measures commonly encountered with control of airborne solvent exposures. The project consisted of two parts: The first part included a literature review using commonly known databases such as the ECEL database (Exposure Control Efficacy Library), interviews were carried out (section 3.1) with various solvent users, and industry stakeholders such as drum pump manufacturers. The second part of the project involved controlled laboratory studies. Various levels of containment, ventilation, use of drum pumps, and equipment draining and flushing techniques were evaluated. The overall goal was to compare measured data against exposure reduction efficiencies previously suggested by ESIG for typical Risk Management Measures (RMMs) used in solvent vapour control.

Findings from the first part of the project showed that although a number of literature search sources can be found with exposure data, only a limited amount of useful information could actually be extracted. The ECEL database (see Table 7 and Appendix B) was found to contain many datasets not representative for solvents. Contextual information was partly lacking and therefore not useful for understanding the basis for the wide range of exposure reduction values. As a result the database was considered inadequate for the context of this effort. Information gathered via interviews was only of qualitative value. Therefore an experimentally based study was initiated. A study plan and measurements were carried out to evaluate the impact of common RMMs.
The second phase of this project included an experimental study (chapter 4) to obtain information on the effectiveness of selected risk management measures (RMMs) from laboratory based simulations.

The RMMs for evaluation were selected on basis of the risk management measures suggested by ESIG and previously used in their CSAs and described by certain standard phrases. The tasks reproduced in the laboratory were based on their compatibility with these identified RMMs and their representativeness for the solvent sector. On this basis general transfer activities were chosen, which can give comparably high exposures under uncontrolled conditions and are widely applied in all industry sectors related to solvents and solvent containing products.

Three main solvent transfer related scenarios were addressed: 1. Gravity transfer; 2. Drum pump transfer and 3. Drain and flush. The effectiveness of selected RMMs, such as local ventilation and / or enclosure, were investigated in the respective exposure scenarios (ES).

The risk management measures were evaluated by comparing the concentration of solvent vapour emissions for these scenarios to a worst case baseline scenario in order to obtain an exposure reduction efficiency (see Table 1). Two baseline scenarios were identified, one for comparison with the gravity and drum pump transfers (ES1), and a second for comparison with the drain and flush transfer (ES8 – see sections 4 and 5). Various RMM options were assessed by comparing the different scenarios against each other in addition to the baseline conditions to provide further granularity on the influence of different measures (see Table 17).

The experimental data gathered from the simulation studies appear to support exposure reduction efficiencies proposed by ESIG exposure science experts.

The results of the experiments (see section 4.3.1 and 6) showed that;

- The application of vented containment could reduce the solvent exposure for gravity transfer by > 99 %

- The change from gravity to drum pump transfer resulted in an average exposure reduction of 93.5 % increasing to up to 99.5 % when vented partial containment was provided.
- The drain and flush simulations showed an average exposure reduction of 95 %.

Thus, both enclosed and ventilated gravity transfer and drum pump transfer can reach exposure reduction efficiencies above 90%.

The assessed effectiveness of the selected RMMs are only valid for the specific process of solvent transfer. The experimental data gained during the simulation studies confirmed the suggestions originally made by ESIG.
The measured values show that even higher efficiencies may be capable of being reached when the task is undertaken in a well-controlled setting. Together with the results of the literature research, this indicates that the assessed situation and all exposure parameters have to be considered in order to ensure that the expected exposure reductions will be met.

Table 1: Comparative overview of gravity transfer and drum pump transfer scenarios to the baseline scenario #1 (for further information and other comparisons see also Table 17)

Scenario	Typically associated phrases (see also section 2) and experimental aspects (in brackets) represented by comparison	Basis for comparison	Mean calculated effectiveness (% reduction)
Gravity transfer of solvent between open containers, with no enclosure and no room and no exhaust ventilation (#1)		NA	NA
Gravity transfer			
Gravity transfer between open containers with ventilation (room and exhaust) and partial enclosure (inside open fume cupboard) in place (#2)	E60 (open fume cupboard, exhaust and room ventilation switched on)	Scenario #2 with scenario #1	98.8
Gravity transfer between open containers with ventilation (room and exhaust) and full enclosure (inside closed fume cupboard) in place (#3)	E61 (closed fume cupboard, exhaust and room ventilation switched on)	Scenario #3 with scenario #1	No observable ethanol exposure (>99)
Gravity transfer between open containers, with no enclosure but LEV (elephant trunk) and room ventilation in place (#4)	E54; or E66 and room ventilation (LEV + room ventilation)	Scenario #4 with scenario #1	97.1
Drum pump transfer			
Drum pump transfer – restricted size of openings (lids closed – standard for solvent transfer); no exhaust and no room ventilation in place (#5)	E53, (E68) (drum pump (with closed container lids))	Scenario #5 with scenario #1	93.5
Drum pump transfer – restricted size of openings (lids closed – standard for solvent transfer); partial enclosure (inside open fume cupboard) and ventilation (room and exhaust) in place (#6)	E53 (E68) and E66 (drum pump (with closed container lids) + open fume cupboard, exhaust and room ventilation switched on)	Scenario #6 with scenario #1	99.5
Drum pump transfer – restricting size of openings (lids closed – standard for solvent transfer), no enclosure (outside fume cupboard),	E53 (E68) and room ventilation (Drum pump (with closed container lids) +	Scenario #7a with scenario #1	96.4

closed but operating fume cupboard and room ventilation in place (#7a)	general room ventilation + closed but operating fume cup-board)		
Drum pump transfer – restricting size of openings (closed lids – standard for solvent transfer), no enclosure (outside fume cupboard), exhaust system (elephant trunk) and room ventilation in place (#7)	E54 or E66, and E53 (E68) and room ventilation (LEV + Drum pump (with closed container lids) + general room ventilation + closed but operating fume cup-board)	Scenario #7 with scenario #1	98.9
Draining and flushing			
Drained container (#8)		NA	NA
Sampling of flushed container with no exhaust system and no room ventilation in place (#9)	E55 (Working on flushed equipment)	Scenario #9 with #8	95.2

2 INTRODUCTION AND PROJECT BACKGROUND

Under REACh exposure assessments for consumers, workers and the environment have to be provided and documented for hazardous substances. For this purpose measurements or exposure models can be used. Tier 1 models offer an easy way of assessing exposure and require minimal input parameters. These models are designed to be easy to use and aim to provide conservative results. An example is the ECETOC TRA model, which can be used for consumer, occupational and environmental exposure risk assessment. The ECETOC TRA model is recommended by the current ECHA guidance on occupational exposure assessment under REACh [1].

ECETOC TRA has been used since 2003. The current version 3, was released in 2012 (TR93, TR107, TR114 [2-4]). The TRA is also implemented in CHESAR (CHEmical Safety Assessment and Reporting tool), an assessment tool that has been developed by ECHA in order to carry out chemical safety assessments (CSA) and facilitate the development of exposure scenarios (ESs) chemical safety reports and safety datasheets. The ECETOC TRA uses the descriptor system recommended by ECHA (guidance document R12 [5]) in order to describe exposure scenarios, i.e. in the case of the occupational settings, the PROC system is applied. An overview of implemented parameters is given in Table 2.

Table 2: ECETOC TRA v.3: Implemented parameters

		exposure reduction
molecular weight	free number	linear dependence (ideal gas law)
dustiness	high / medium / low	included in initial exposure estimate
vapour pressure	high / medium / low / very low	included in initial exposure estimate
process description (PROC no)	PROC 1-25 according to the descriptor system	included in initial exposure estimate
process temperature (PROC 22-25)	process temperature relative to melting point	included in initial exposure estimate via fugacity
process temperature (PROCs 1-21)	vapour pressure at process temperature is entered high / medium / low / very low	included in initial exposure estimate
type of setting	industrial / professional	included in initial exposure estimate and LEV efficiency
ventilation	indoor without LEV indoor with LEV	0% PROC specific
	good general ventilation enhanced general ventilation good general ventilation + LEV enhanced general ventilation + LEV	30% 70% PROC specific PROC specific
	outdoor	30%
RPE, respiratory protection equipment	90 % efficiency 95 % efficiency	90 % 95 %
gloves	Any gloves / gauntlet without permeation data and without employee training	0%
	Gloves with available permeation data indicating that the material of construction offers good protection for the substance	80 %
	Chemically resistance gloves	90 %

	with basic employee training	
	Chemically resistant gloves in combination with specific activity training (e.g. procedures for gloves removal and disposal) for tasks where dermal exposure can be expected to occur	95 %
Concentration (w/w)	< 1% 1-5% 5-25% > 25%	90 % 80 % 40% 0%
duration	< 15 min 15-60 min 1-4 h > 4 h	90 % 80 % 40% 0%
	Short term 15 min	400% (exposure peaks)

ECETOC TRA v.3 and/or CHESAR have also been used for the development of chemical safety assessments for solvents, using as their basis the generic exposure scenarios (GESs) developed by ESIG / ESVOC[1]. In applying GESs, those operational conditions and risk management measures (RMMs) that are described and offered by ECETOC TRA have been used as the starting point to refine and describe the exposure scenarios. However, many of the TRA's exposure controls relate to ventilation (general ventilation and local exhaust ventilation, see Table 2) and, for some scenarios, the application of the restricted range of TRA RMMs was not considered to be sufficient to enable commonly employed techniques encountered when handling solvents to be factored into the CSA (and communicated in any related ES).

In order to address this problem ESIG identified a range of risk management measures which are commonly encountered when handling solvents. A starting point for the work was to list exposure controls applied for handling petroleum substances. These are described by CONCAWE in report 11/12 [6]**.** Table 5, Table 18 and Table 19 summarise these measures together with suggested exposure reduction values for inhalation exposure. They include various levels of containment in combination with ventilation [7], the use of drum pumps [7] for filling procedures and draining and flushing procedures for cleaning and maintenance operations [6, 8]. Although the derivation of the defaults listed below has been based on published information and expert judgement, there is a paucity of empirical data on effectiveness. ESIG therefore determined that REACH CSAs would benefit if the assumptions could be affirmed or not with experimental data, especially in relation to solvents.

[1] http://www.cefic.org/Industry-support/Implementing-reach/Guidances-and-Tools1

Table 3: Levels of containment

Phrase Description	EUPhrаC Phrase Codes	Assigned Exposure Reduction (%)	Justification	Boundary of Application
Minimise exposure by extracted full enclosure for the operation or equipment	E61	90 (prof) / 95 (industrial)	Properly designed and maintained extract ventilation can be an effective means for capturing and controlling exposure [9]. The effectiveness of extract ventilation is strongly influenced by its location relative to the emission source and characteristics of the extraction device itself, such as the size of openings where emissions can be released [7]. A value of 90/95% has been assigned consistent with that for where LEV is applied in the TRA.	All PROCs
Minimise exposure by partial enclosure of the operation or equipment and provide extract ventilation at openings	E60	80 (prof)* / 90 (industrial)*	Properly designed and maintained extract ventilation can be an effective means for capturing and controlling exposure (HSE, 2011). The effectiveness of extract ventilation is strongly influenced by its location relative to the emission source and characteristics of the extraction device itself [10]. A value of 80/90% has been assigned consistent with that for where LEV is applied in the TRA.	All PROCs except 7 and 11 (spray operations)
Restrict area of openings to equipment	E68	80 (all uses)	The release of emissions can be significantly reduced if the size of openings can be restricted [7]. A value of 80% has been assigned consistent with the lower end of the TRA LEV .	All PROCs except 7 and 11 (spray operations)

* Except for PROCs 7/11 and 8b where an efficiency of 95% is applied in all industrial settings (and 90% is applied in professional settings)

Table 4: Use of drum pump

Phrase Description	EUPhraC Phrase Codes Covered	Assigned Exposure Reduction (%)	Justification	Boundary of Application
Use drum pumps	E53	80 (all uses)	The use of drum pumps for the transfer of liquid products has a significant impact in reducing exposures. Drum pumps essentially enable the closed transfer of the product and serve to reduce both inhalation and dermal exposures. Data on their inherent effectiveness is available from manufacturers (e.g. Lutz), although poor practices (such as rapid pump withdrawal) can reduce this. A value of 80% has been assigned consistent with that for basic LEV.	Only intended to be applied to material transfer activities for liquid substances (essentially PROCs 3, 4, 8a and 8b). Relevant for transfer of moderate volumes (drums, IBCs).

Table 5: Draining and flushing of equipment

Phrase Description	EUPhraC Phrase Codes Covered	Assigned Exposure Reduction (%)	Justification	Boundary of Application
Drain down and flush system prior to equipment break-in or maintenance	E55	90 (industrial)	Based on data from comparable refining maintenance activities [6]. The flushing element of the SOP serves to further reduce the likelihood that significant amounts of material will be emitted during the operation. If (inert) purging is also employed in the procedure, then resulting exposures can be expected to be lower still.	Only intended to be applied to maintenance activities (essentially PROC 8a) in industrial settings
Drain down system prior to equipment break-in or maintenance or Drain or remove substance from equipment prior to break-in or maintenance	E65 or E81	80 (all uses)	Based on data from comparable refining maintenance activities [6]. The phrases only address drain down and do not include flushing. Associated exposure reduction is hence less than that for E55.	Only intended to be applied to maintenance activities (essentially PROC 8a)

The purpose of this project was to evaluate the exposure reduction efficiency from different levels of containment / ventilation, drum pumps and draining and flushing of equipment. This project consisted of two parts. The first part included a literature review using commonly known databases, the ECEL database (Exposure Control Efficacy Library) and other sources of published reports (section 3). The second part of the project involved experimental studies designed to replicate these risk management measures in a reproducible experimental setup (section 4).

The overall goal was to determine whether the experimental findings are consistent with the values previously proposed and show that the measures represent a suitable way to reduce exposure to solvents.

3 AVAILABLE INFORMATION

3.1 COLLECTION AND EVALUATION OF PUBLISHED INFORMATION

A large collection of measured exposure data describing the effect of risk management measures is contained in the Exposure Control Efficacy Library (ECEL[2]). The development of this library included an evaluation of 433 datasets and has been published by Fransman et al. [11] (see Table 6). However, although the general level of detail of the available contextual information is comparably high, no evaluation of the datasets concerning the source or type of exposure was provided by Fransman et al. For example, solids, dust exposure, and industrial processes irrelevant to solvents are included in the analyses. Moreover, only a limited number of the standard phrases used within the ESIG CSAs (complete / partial enclosure) seems to be represented within ECEL. Some datasets are included where the implementation of a risk management measure seemingly led to an increase of exposure, which according to Fransman et al. suggested poor work practice (negative boundaries of confidence intervals).

Thus, the single datasets within ECEL have been re-evaluated considering solvent exposure and risk management measures of interest. The results have been supplemented by more recently published scientific literature gathered via reputable search engines (WebOfScience, SciFinder, Scopus).

Table 6: Previous analyses of the ECEL database as done by Fransman et al. [11]

RMM	*n*	Estimated efficiency (average %)	95% confidence interval (%)
Enclosure	14	50	4 to 74
Complete	3	86	30 to 97
Partial	6	23	-103 to 70
LEV	280	82	78 to 84
Exterior	65	81	75 to 86
LEV + Enclosure	9	86	69 to 94
Integrated	133	87	84 to 90
Mobile	4	61	-28 to 88
Vapour collection	19	64	23 to 83
Specialized ventilation	14	87	73 to 94
Specialized booth	1	94	37 to 99
Clean-zone worker	6	86	64 to 95
Miscellaneous	7	85	47 to 96
General ventilation	42	43	17 to 61
Natural	9	31	-56 to 70
Mechanical	31	46	17 to 65
Suppression techniques	69	83	77 to 88
Wet suppression	32	84	75 to 89
Capture sprays	25	88	80 to 93
Stabilization	12	58	-3 to 83
Separation of workers	14	87	71 to 94
Complete	9	90	75 to 96
Partial	5	71	-31 to 94

[2] http://ecel.intelligentobjects.nl/Account/SignIn

The search criteria and number of results are shown in Table 8 and suggest a sufficient amount of available information exists to make broad conclusions about the effectiveness of certain types of RMM. However, the evaluation of the refined results also revealed that a large fraction of documents do not directly relate to the efficiency of RMMs encountered in the solvent industry. Publications which were considered to be useful where collected in an Excel database (see separate Excel file, Appendix B and explanations below).

Publications on the following topics were considered to be out of scope for this project and therefore not further evaluated:

- Toxicology based publications (immune effects, drug approval, etc.)
- Efficacy of insecticides
- Exposure to UV radiation or nuclear radiation in power plants,
- "Cost containment"; minimisation of costs
- Containment of diseases (Ebola, SARS etc.)
- Non-occupational exposure (e.g. lead in house dust, environmental exposure)
- Noise exposure
- If RMMs have been investigated in the following ways:
    - quantitative, but no exposure measured (e.g. velocities)
    - only visual examination (e.g. smoke extraction)
    - gradient measurements (e.g. in dependence of distance to hood) – interesting but difficult to use for derivation of efficiency as the personal component is missing. Obviously at a certain distance the "efficiency" will become 100%.
- Influence of exposure to chemical on photosynthesis or other processes, diseases etc.
- Odour containment
- Patents or product descriptions (e.g. new type of drum pump for sale)
- Solvent emission by plants and fungi
- Methane emission by cattle
- Other topics which are obviously not exposure related (e.g. containment of goats with barbed wire, the discipline of space in a Japanese fitness club)

In addition to these two approaches (ECEL and general literature databases) a link to the CEHD (chemical exposure health data) database[3] as well as a publication [12] about this database were evaluated. However, both the evaluation of the Lavoue et al. and screening of CEHD showed that information stored in the database is insufficient for this project. There are no job descriptions or job titles and no information about risk mitigation measures. Only an evaluation of exposure to certain substances for a given industry area would in general be possible using the SIC codes stored in the database. However, as long as no task or job description is available no efficiencies for RMMs can be obtained.

Another database mentioned by Lavoue et al. is the IMIS database (Integrated management information system)[4]. This database is supposed to contain more contextual information, in particular job descriptions. However, it is not known what level of detail is given on RMMs, as the database is not publicly available. Excerpts from this database can be ordered from OSHA according to Lavoue et al., however, there is no contact person given. Moreover, a fee has to be paid and preparation time for the excerpt can be from several weeks up to a few months. This approach was therefore not pursued.

[3] https://www.osha.gov/opengov/healthsamples.html

[4] https://asprod06.osha.gov/

3.2 RESULTS OF PUBLISHED INFORMATION

Results were extracted and evaluated as described in the following subsections. The results have been summarised in an Excel database (see Appendix B).

3.2.1 Containment

Some information was found in the course of the literature search and has been collected (together with information extracted from ECEL) into an Excel file. The steps of the evaluation process are documented to provide clear transparency:

- **sheet 1** ("enclosure complete") contains all publications which have been actually evaluated (i.e. not only title and abstract). Efficiency values have been included as far as possible. If several options were possible for one study, personal sampling was preferred.
- **sheet 2** ("enclosure selected 1") contains a selection of these publications: All without quantitative results on efficiency were removed; all publications with efficiencies below 0% were removed. It was obvious some kind of failure (bad practice, flaws in study design etc.) was present.
  All data points have been categorised according to their relevance (not relevant, maybe relevant, relevant). The categorisation has been done on the basis of the available information on relevant industry areas, tasks and substance / exposure type measured.
- **sheet 3** ("enclosure selected 2") contains all data points categorised as "relevant" or "maybe relevant", rearranged according to the ESIG standard phrase assigned. Average efficiencies for each combination of industry area and phrase were calculated. No data points for phrase E68 (restrict area of openings to equipment) were identified. Often insufficient information was available to assign a type of setting (professional/industrial) – in these cases the values representing both or unknown type of settings were grouped together and an average was calculated.

Efficiency values reported by ESIG for the three containment related phrases were 0.2 (80% exposure reduction) for E68 (restrict areas of openings) and E60/professional (partial enclosure + extract ventilation); 0.1 (90% reduction; E60, industrial; E61 (full enclosure for the operation + extract ventilation), professional); and 0.05 (95% reduction; E61, industrial).
The results from the evaluated literature are as follows (see also **sheet 4 "summary"**):

Table 7: Comparison of evaluated phrases, ESIG exposure reduction values and information found in literature (see also Appendix B for details).

industry area	phrase	type of setting	efficiency (from literature sources, average)	ESIG efficiency (modifying factor, see Table 3)	route	Number of database items [References]
construction	E60	professional	0.22	0.2	inhalation	3 [13]
metal / metallurgical industry	E60	both / not identified	0.47	0.1-0.2	inhalation	1 [14]
metal / metallurgical industry	E60	industrial	0.27	0.1	inhalation	4 [15, 16]
metal / metallurgical industry	E61	both / not identified	0.18	0.05-0.1	inhalation	4 [17-19]
metal /	E61	industrial	0.29	0.05	inhalation	11 [15, 16, 20]

metallurgical industry						
automotive	E60	both / not identified	0.86	0.1-0.2	inhalation	10 [21]
agriculture	E61	both / not identified	0.28	0.05-0.1	inhalation	1 [22]
agriculture	E61	professional	0.06	0.1	inhalation	7 [23-25]
manufacture of chemicals	E61	both / not identified	0.15	0.05-0.1	inhalation	2 [26]
paint manufacture	E60	both / not identified	0.37	0.05-0.1	inhalation	4 [27]
paint / coatings	E60	professional	0.5	0.2	inhalation	1 [28]
fuels	E60	professional	0.31	0.2	inhalation	7 [29, 30]
rubber industry	E60	both / not identified	0.57	0.1-0.2	inhalation	2 [31, 32]
rubber industry	E60	both / not identified	0.32	x	total exposure	1 [31]
rubber industry	E60	both / not identified	0.68	x	dermal	1 [32]
health care / medicine	E60	both / not identified	0.1	0.1-0.2	inhalation	3 [33-35]
not defined	E60	both / not identified	0.11	0.1-0.2	inhalation	16 [36-38]

The results suggest that the efficiencies chosen by ESIG may be overoptimistic for some of the evaluated industry areas. Cases where measured values and ESIG suggestions were comparable include agriculture, not defined areas, and health care.

For purpose of database evaluation some simplifications were made. Datasets are considered to be “ideal” if they include all necessary contextual information, and suitable industry areas / tasks relevant to solvents as well as suitable risk management measures are involved. However, this was not the case for all datasets finally included into the evaluation (Table 7 and sheet 4 of Excel database) due to the limited amount of available data. Some publications may introduce bias due to higher exposure results caused by poor occupational practice (e.g. industry area “automotive”).
Therefore, the available database cannot be considered to be of good quality. However, it may support the discussion of corresponding results.

3.2.2 Drum pumps

No published studies were found containing relevant information about the efficiency of drum pumps.

3.2.3 Draining / flushing

No published studies were found containing relevant information about the efficiency of draining / flushing of equipment.

Table 8: Literature search: documentation of search criteria.

		Number of results		
Keyword	**Refinement**	**Web of Science**	**Scifinder**	**Scopus**
containment (1990 or newer)		15106	21205	24835
	"exposure reduction"	0	93	1
	efficiency AND exposure	24	32	136

	efficacy AND exposure	26	36	182
	"emission reduction"	42	104	140
enclosure (1990 or newer)		17110	18271	20630
	"exposure reduction"	2	89	4
	efficiency AND exposure	29	30	115
	efficacy AND exposure	11	13	62
	"emission reduction"	4	89	30
"drum pump"		1	9	17
"exposure reduction" AND flush		0	98	0
"exposure reduction" AND drain		1	392 (AND "occupational exposure": 11)	0
"exposure reduction" AND maintenance		28	1327 (AND "occupational exposure": 127)	23
"exposure reduction" AND solvent		9	1554	6
"control measure" AND solvent		8	2293	72
"control measure" AND solvent AND "exposure reduction" (1990 or newer)		x	28	x

3.1 INFORMATION FROM INDUSTRY

The following industry sectors and associations were contacted and asked for general information on solvent handling and risk management measures as well as quantitative exposure data:

- drum pump manufacturers
- formulators and other companies handling solvents
- the metalworking fluid sector
- the adhesives association
- the association for paints and varnishes
- Employer's Liability Insurance Association for Wood and Metals
- IFA (Institut für Arbeitsschutz)
- BAuA (Federal Institute for Occupational Safety and Health)

Although most contact persons were in general willing to share information, there was only few quantitative exposure data available and none could be used for this project. Most companies were only able to offer qualitative information and a general opinion on measures which are considered to reduce exposure (e.g. drum pump manufacturers).
Many companies (e.g. formulators, metalworking sector) indicated that the main factor determining the level of containment or the RMMs is the flashpoint, whereas the main concerns are usually related to the explosion hazard and not human exposure to the substance itself. Solvent transfer or refilling is often done via hard connections, i.e. fixed, closed lines dedicated to one solvent.
In general, companies often indicated that they used substitution as preferred risk mitigation measure, i.e. replacement of the solvent by water or other solvents with higher flash points or to reduce disposal costs. An example is the adhesives association, where solvent use is being phased out as far as possible.

Concerning the adhesives industry it was also noted that process equipment in their industry was most often a closed system and impossible to measure “without containment”. One application where solvents are still used is in the production of adhesive tapes, where a combination of enclosure under nitrogen atmosphere and additional exhaust ventilation is used in modern manufacturing sites. Some older and less advanced sites may still exist, however, enclosed systems as described above are considered to be state of the art in this kind of facility.

A project underway at **BAuA** (Federal Institute for Occupational Safety and Health) in cooperation with the VCH and member companies may provide in future exposure control information via VSK[5]. In the course of this project exposure measurements at 10 types of solvent filling stations (filling of drums, IBCs, canisters) using various solvents have been done. Mostly filling stations with local extract ventilation have been sampled, few situations involved drum pumps. No closed systems have been measured.
It was not possible to obtain the individual measurements, however, results were published [39] and showed concentrations between 0.44 and 49.1 ppm (sampled at LEV, Jerrycans, Drums and IBCs) and an overall mean of 13 ppm[6] for personal sampling. The publication focuses only on stations equipped with LEV ("control strategy 2" according to the EMKG; no publication of drum pump measurements).

The **association for paints and varnishes** indicated that a project on RMMs was conducted with the **Federation for Raw Materials and Chemistry[7]** some years ago, resulting in a guidance document about the minimisation of solvent exposure in paint/varnish production [40, 41]. This project included the documentation of RMMs in varnish production, e.g. containment (cover of mixing tanks etc.) and extract ventilation. Based on exposure measurements primarily for cleaning activities specific RMMs were advised within the guide.
The association for paints and varnishes asked the companies which participated in the development of this guidance document to report their success with the measures that were suggested in the course of the project. However, it was felt that data could only be shared by individual companies, i.e. the data owners, and not by the association for paints and varnishes or the Bundesgenossenschaft. Some feedback was received from individual companies, however, no useful information could be extracted.

The **"Institut für Arbeitsschutz (IFA)"[8]** was contacted in order to explore the availability of useful data within the MEGA exposure database[9]. However, a short check of the available data in MEGA revealed that not enough detailed contextual information is available in the majority of the datasets. Datasets (or pairs of datasets measured at the same facility before and after installation) could not be found. This is also consistent with the general experience of IFA employees. Furthermore, they are not allowed to submit company contact details. Therefore IFA sent us an official answer stating they were not able to help with this project.

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[5] ("Verfahrens- und stoffspezifische Kriterien (*VSK*) für die Gefährdungsbeurteilung" publications covering process- and substance specific criteria for risk assessment)
[6] 49 samples "HIT", i.e. sampled concentration within EMKG prediction or lower: Mean 5 ppm; 21 samples "FAIL": Mean 31.8 ppm Given by Hebisch et al., overall mean estimated from these values.
[7] Bundesgenossenschaft Rohstoffe und Chemie
[8] German Institute for Occupational health and safety of the statutory accident insurance
[9] Measurement data relating to workplace exposure to hazardous substances = Messdaten zur Exposition gegenüber Gefahrstoffen am Arbeitsplatz

3.2 PART ONE CONCLUSION FROM INTERVIEWS AND AVAILABLE INFORMATION

The literature review and ECEL database evaluation revealed information available on exposure reduction efficiencies on certain risk management measures, for example information on the effect of containment and different forms of ventilation on inhalation exposure. However, most literature data are not solvent specific and it is not known to what extent the associated findings are comparable. Contextual information may be incomplete in some cases and thus, it is difficult to evaluate the datasets extensively. As an example, some datasets have been identified with negative exposure reductions (i.e. exposure increases resulting from the introduction of risk management measures), but usually no final conclusion on the reasons could be made. No experimental or empirical data could be identified concerning the use of drum pumps or draining / flushing of equipment.

The interviews with drum pump suppliers were generally informative, however we were unable to obtain any quantitative data regarding exposure reduction pertaining to their equipment.

Information obtained from other representatives of the solvent industry was mostly of similar quality. Quantitative data may exist in some companies or organisations but could not be used for the project.

It can be concluded that no sufficient quantitative information is currently available for any of the evaluated phrases. It was therefore decided to move forward to the experimental part of the project and develop a study plan to further evaluate the influence of risk management measures on inhalation exposure to solvents.

4 EXPERIMENTAL STUDIES

4.1 INTRODUCTION

Due to limited amount of useful information that could be extracted either from Part one investigations using the Excel database or via company interviews, laboratory based experiments were initiated. A study plan was developed and measurement studies were carried out to evaluate the exposure reduction impact of specific RMMs.
Simulation of selected RMMs in a laboratory environment were considered to be the most appropriate way to fill in the missing gaps. Hence, a selection of defined risk management measures corresponding to the phrases and their implementation in scenarios and simulations was compiled.

In a pilot study the parameters regarding experimental set-up, data acquisitions / sampling and evaluation were established. In the final study three solvent transfer tasks were evaluated (see also **Table 9**): 1. Gravity transfer (phrases E60, E61, E54, E66 and baseline); 2. Drum pump transfer (phrases E53, E66, E66) and 3. Drain and flush (phrase E55). The effectiveness of selected RMMs, such as ventilation and / or enclosure, were also investigated. Ethanol was chosen as the model solvent based on its volatility, solubility in water, low hazard and wide application. Ethanol vapours released during a simulation were monitored with an IR-spectrometer. A reasonable worst case scenario was established as baseline and used for comparison to the different RMM scenarios to determine the relative effectiveness of a given RMM.

4.2 METHODS

4.2.1 Experimental set-up

A selection of scenarios / exposure situations (**Table 9**) was developed on basis of the following criteria:

- all evaluated phrases should be covered with a minimum of experiments
- the tasks reproduced in the laboratory should be compatible with the corresponding phrases (see section 2)
- the tasks should be representative for the solvent sector, i.e. handling of solvents and solvent containing products.

As a representative task for most phrases, which is commonly applicable in all industry areas related to solvent use, transfer activities were selected (e.g. PROC8a, 8b). This is also an activity where reasonably high exposure values might be expected under uncontrolled conditions due to large surfaces and the nature of many open transfer activities (pouring might lead to air movement, high evaporation, spilling of substance is possible). The phrases related to containment and drum pump transfer (see above) are all compatible with this task, where the level of containment and ventilation can be adapted by either working in a fume hood (sash open or closed) or with LEV (elephant trunk). In both instances the spatial conditions of the laboratory environment required room ventilation to be operated, a prerequisite for the optimal functioning of LEV and fume hood.

Flushing and draining is a measure usually applied to pieces of equipment before cleaning and maintenance activities, i.e. before an installation is opened. A drum was used as a surrogate for generic parts of equipment which might be opened in industry and therefore be a source of solvent evaporation. The scenario evaluated is the drained and flushed drum (ES9), which can be compared with a merely drained drum (ES 8). Technically, this comparison only represents the “flushing” but not the “draining” part of the proposed risk management measure. However, draining is, due to the individual design of industrial equipment less easy to reproduce in a laboratory and a base configuration scenario without draining may – depending on this equipment – be represented by a full, open drum, ES1 or other, not evaluated scenarios. It was therefore decided not to evaluate this aspect any further.

With this approach it is possible to evaluate several RMMs under comparable conditions with a small number of experiments and a pragmatic set-up. The single scenarios and experimental set-ups were discussed with the whole project team and underwent several iterations of refinement before finalisation. Further refinement of parameters and processes was done in the course of a pilot study in order to improve representativeness and reproducibility of the results.
As a baseline scenario the open gravity transfer from one drum to another without containment and ventilation has been used (ES1). This scenario represents a worst case as no risk management measures were applied. However, other scenarios can be used for comparison (“base configuration scenario”) in order to evaluate additional influences, e.g. effect of ventilation and spatial containment (ES6) on drum pump transfer (ES5), or in cases were another scenario represents the logical worst case for comparison (e.g. draining and flushing; ES8 vs ES9).

The influence of different risk reduction measures (RMMs) on the emission of ethanol vapours during solvent transfer (50 L) from a reservoir container into a collection container was investigated. For this a selection of standard RMMs and their implementation in nine different scenarios was compiled (**Table 9**). All simulations were conducted in a room holding a 2-451-GAND fume hood. The faultless operation of this fume hood required an additional air supply into the room to prevent the build-up of negative pressure in the room (air-exchange rate of approx. 14-18 per). This air supply is provided by the installed room ventilation which has to be switched on when the fume hood is to operate properly (Fig. 1). In general the room ventilation circulates the additional air via an inlet (approx. 1000 m^3/h) and an outlet (approx. 600 m^3/h). In the event of the fume hood being switched on the outlet valve of the room ventilation will be closed and all air supplied by the room ventilation will be removed by the fume hood (approx. 1100 – 1200 m^3/h).

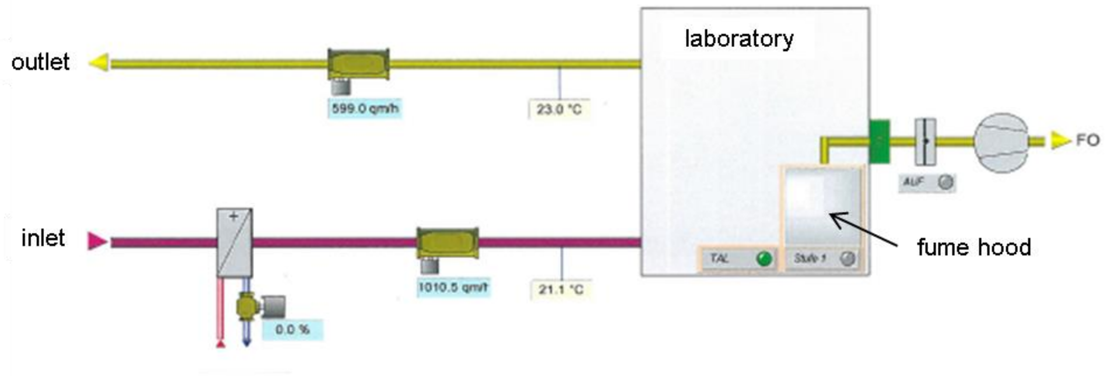

Fig. 1 Schematic of room ventilation and fume hood in the laboratory.

The ethanol vapours released during the individual simulations as well as the water content in the air were monitored with a portable IR spectrometer. The water content in the air was monitored as an indicator for changes in the atmosphere. The observed water concentration varied between 0.2 and 0.7 vol-%.

During this study simulations were conducted for nine different scenarios (**Table 9**). The experimental set-up was either placed inside the operating fume hood (Scenario #2; 3 and 6; **Table 9**) or outside the fume hood. Simulations conducted outside the fume hood were either conducted without any exhaust and room ventilation in place (scenario #1; 5; 8 and 9) or with the application of a local exhaust system (Scenario# 4 and 7). The air flow at the entrance of the operating local exhaust system (LEV) was approx. 1 m / s. The local exhaust system was an in-house assembled “Elephant Trunk” utilising the 2-451-GAND fume hood. This meant that the entire room was ventilated at an air exchange rate of approx. 14-18 per hour. An additional scenario (ES7a) was set-up to obtain an initial estimate on the effect of room ventilation. This scenario set-up was identical to the one for ES7 with the only difference being that the opening of the local exhaust system (“Elephant Trunk”) was sealed.
The experimental set-up of most scenarios was captured in photos shown in **Fig. A 1** and **Fig. A 2** (Appendix C). An overview of the implementation of the individual scenarios into laboratory based simulations are given in Table 20 to Table 25 (**Appendix C**).

The pilot study had revealed that uncontrolled air movement (e.g. the movement of personnel involved with the experiment) in the room can cause distinct variations of the measured ethanol concentrations for one given scenario and its simulations. Those variations were thought to be the result of the creation of eddies and the consequent formation of “vapour pockets” in the room. In order to minimise this phenomenon and thereby improving the reproducibility of the simulations within one scenario, an artificial wind channel was installed. This wind channel consisted of a card board box and a fan, creating an air flow of approx. 1.5 m / sec at the collection container opening. In addition, all other movements in the room (e.g. by the researchers present in the room) were kept to a minimum to improve reproducibility. Also with respect to reproducibility, the sampling probe was always positioned at the same distance from the exposure source (here: 100 cm) and always at the same height from the floor (here: 95 cm).

For each scenario replicate simulations were conducted with a minimum of three repetitions. Care was taken before starting a new simulation to confirm the ethanol background level in the room was reached. This was achieved by venting the room.

Table 9: Phrases and Scenarios. Phrases describe the given scenarios in relation to the corresponding worst case (usually ES1; except for drain and flush).

ES #	Phrase	Scenario
1		Baseline – Gravity transfer (splash loading) from an open container into another open container with no exhaust and ventilation system in place. Outside of fume cupboard.
Gravity Transfer		
2	Phrase: E60 'Minimise exposure by partial enclosure of the operation or equipment and provide extract ventilation at openings'	Open gravity transfer (splash loading) with partial enclosure (inside open fume cupboard) into a container. Room ventilation and fume cupboard switched on.
3	Phrase: E61 Minimise exposure by extracted full enclosure for the operation or equipment	Open gravity transfer (splash loading) with full enclosure (inside closed fume cupboard) into a container. Room ventilation and fume cupboard switched on.
4	Phrase: E54 'Provide extract ventilation to points where emissions occur' Phrase: E66 'Ensure material transfers are under containment or extract ventilation'	Gravity transfer (splash loading) from an open container into another open container – application of a local exhaust system (LEV, elephant trunk) and no enclosure (outside fume cupboard). Room ventilation and fume cupboard[10] switched on.
Drum Pump Transfer		
5	Phrase: E53 ' Use of drum pump' (Phrase: E68, 'Restrict area of openings to equipment')[11]	Drum pump transfer (lids on containers) with no exhaust and no room ventilation– accurate use of drum pump (submerged loading). Outside of fume cupboard.
6	Phrase: E66 'Ensure material transfers are under containment or extract ventilation.' (Phrase: E68, 'Restrict area of openings to equipment')[11] Phrase: E53 ' Use of drum pump'	Drum pump transfer (lids on containers) with partial enclosure (inside open fume cupboard) – accurate use of drum pump (submerged loading). Room ventilation and fume cupboard switched on.
7	Phrase: E54 'Provide extract ventilation to points where emissions occur' Phrase: E66 'Ensure material transfers are under containment or extract ventilation.' (Phrase: E68, 'Restrict area of openings to equipment') [11] Phrase: E53 ' Use of drum pump'	Drum pump transfer (lids on containers), room ventilation and a local exhaust ventilation system in place (elephant trunk)[10] – accurate use of drum pump (submerged loading). Outside of fume cupboard.
7a	Phrase: E53 ' Use of drum pump' (Phrase: E68, 'Restrict area of openings to equipment') [11]	Drum pump transfer (lids on containers). Room ventilation and fume cupboard (sash closed) were switched on. No local exhaust system was in place.Accurate use of drum pump (submerged loading). Outside of fume cupboard.
Drain and Flush		
8		Base Configuration for scenario 9: Drained container without flushing with no exhaust and ventilation system in place. Outside of fume cupboard.
9	Phrase: E55 'Drain down and flush system prior to equipment break-in or maintenance.'	Flushed container with no exhaust and no room ventilation system in place. Outside of fume cupboard.

[10] The operating fume cupboard was an integral part of the LEV.
[11] Standard handling for solvents.

The 'background' ethanol levels in the test room was set at 5 ppm or lower. For the worst case baseline simulation (ES1) a background concentration of 5 ppm was not feasible and the acceptable background value raised to 25 ppm.

All scenarios involving solvent transfer (i.e. phrases for drum pump transfer and containment) were simulated as follows:

50 L of ethanol were transferred either by gravity (splash loading) or by using a drum pump (submerged loading). The nature of the two different methods resulted in distinct differences regarding transfer time. The gravity transfer took approx. 4 min whereas the use of a drum pump reduced the transfer time down to approx. 40 sec.

The scenarios to address draining and flushing of equipment were simulated as follows:

1. the inside surfaces of the collection container were rinsed with 1x 5 L ethanol representing a just drained container (scenario #8).

and

2. the inside surfaces of the collection container were rinsed with 1x 5 L ethanol followed by rinsing them with 2x 10 L water representing the rinsing of a just drained container (scenario #9)

4.2.2 Equipment and Chemicals

Throughout all simulations bioethanol (Kaminethanol; PN: 10295) was used. A list of all the required equipment is given in **Table 10**.

Table 10: Equipment

Equipment	Supplier
Reservoir container (120 L) with removable lid; two openings: 1) id = 34 cm , 2) id = 4 cm	Ökolube; PN: SP21008
Reservoir container blue (120L) with two bung holes 1.) id = 4cm; 2.) id = 7cm[12]	FassWulf; PN: K206
Collection container (60 L) with removable lid; two openings: 1) id = 34 cm , 2) id = 4 cm	Ökolube; PN: SP21007
Drum pump set "Solvents"	Lutz Pumpen GmbH
Portable IR-Spectrometer	Asynco – Gasmet FTIR Gas Analyser (Model: DX 4015)
Antistatica Kit	Bürkle; PN: 5602-100
Fume hood 2-451-GAND; dimensions: depth (56.5 / 62 cm – 75 cm), width (114.5 cm -120.5 cm), height (max. 214 cm), performance 0 or 1000-1200 m³ / hour)	Köttermann (Model: 2-451-GAND)
Gas collection tube / buffer volume (1 L)	

4.2.3 Data Evaluation

In terms of data evaluation, a simulation is defined as the time period in which the solvent transfer takes place and the measured ethanol concentration at the sampling probe has

[12] The bung hole with an id of 7cm was used for the drum pump transfer whereas the second bung hole remained closed at all times.

reached the respective background concentration. The overall time for a simulation varied with the scenarios.

The ethanol concentration at the sampling probe was recorded every 20 seconds with a portable IR-spectrometer at a wavenumber of 3000 cm^{-1}. The ethanol exposure during each simulation is illustrated in the respective graphs with the ethanol concentrations being plotted against the time of day (**Fig. A 3** to **Fig. A 37**).
The data sets collected this way offer three parameters to assess the effectiveness of the individual RMMs:

1. **Peak ethanol concentration**: The peak concentration is defined as the max. ethanol concentration observed during the simulation period.

2. **Area under the curve (AUC)**: The area under the curve (AUC) is a measure for the total amount of ethanol measured at the sampling probe within the simulation period. If not stated otherwise the time window was set to 13 min and is highlighted by a yellow rectangle in the respective graphs (examples: **Fig. 2** and **Fig. 3**).
   A fixed time window was necessary to allow the comparison of the AUC data between the different simulations and scenarios. Additionally the rational of choosing a time window of 13 min was to ensure that the initial ethanol background levels were reached again after passing through the peak ethanol levels in instances where an operating exhaust / ventilation system was applied. Initial background levels were not reached again, when no exhaust / ventilation system was in place.
   Ideally a 15 min time window would have been chosen but was reduced to 13 min due to a lack of data points for some simulations.

3. **Extrapolated ethanol concentration (EEC)**: The extrapolated ethanol concentration is a value that comes closest to the hypothetical mean ethanol concentration in the room if homogenous distribution of the ethanol fumes in the room were possible. The determination of the EEC is achieved by plotting selected data points (encircled by blue oval) from the descending part of the ethanol exposure graphs against time (in minutes; examples: **Fig. 4** and **Fig. 5**); where time point zero corresponds to the time point when the ethanol transfer was completed. The resulting graph reflects an exponential decay which can be fitted by a trendline with the overall formula: $y = y_0 \exp(-kt)$ with y_0 being the EEC.

   The correct choice of the selected data points for this trendline is crucial and is determined by the constant k of the respective graph. Multiplying k with 60 min results in the air exchange rate (per hour) in the room. To allow a comparison of the data this constant must be kept constant for the given circumstances – room ventilation off or on. For simulations with the room ventilation being switched off the data points were selected that the back calculated air exchange rate was approx. 1 (example: **Fig. 4**). For simulations with the room ventilation being switched on the data points were selected that the back calculated air exchange rate was 11 ± 1 (example: **Fig. 5**).

The decline of the ethanol concentration around the sampling probe was greatly influenced by whether an exhaust / ventilation system was in place. The decline was more rapid when the exhaust / ventilation system was operated and also led to the decline of the ethanol concentration back to the initial background concentration. In instances where no exhaust or ventilation system was in place, the initial background values were not reached. These differences in the time frame explain why in some instance the data points for the calculation of the extrapolated EtOH concentration lie within the time window of the AUC and some outside (examples: **Fig. 2** and **Fig. 3**).
The build-up of ethanol around the sampling probe was very susceptible to the necessary changes in the positioning of the solvent containers between scenarios. Also unavoidable air movements in the room resulting from the movements of the experimenters still had an

impact despite the application of the artificial wind channel. The unpredictability of these factors makes the peak ethanol concentration and therefore also the AUC values unsuitable parameters for assessing the effectiveness of the different RMMs.

The extrapolated ethanol values are less affected as the data points considered for the calculations are recorded after distribution of the ethanol fumes around the sampling probe. Up to a certain degree the distribution process will smooth out unpredictable localised high ethanol concentration events thereby making the EEC a more reliable parameter to assess the effectiveness of the selected RMMs. Therefore all discussions (**chapter 4.3**) concerning the effectiveness of the investigated RMMs will be based on the respective EEC values. An overview of all data, including peak ethanol concentration, AUC and EEC, is given in Table 26 to Table 30 (Appendix C).

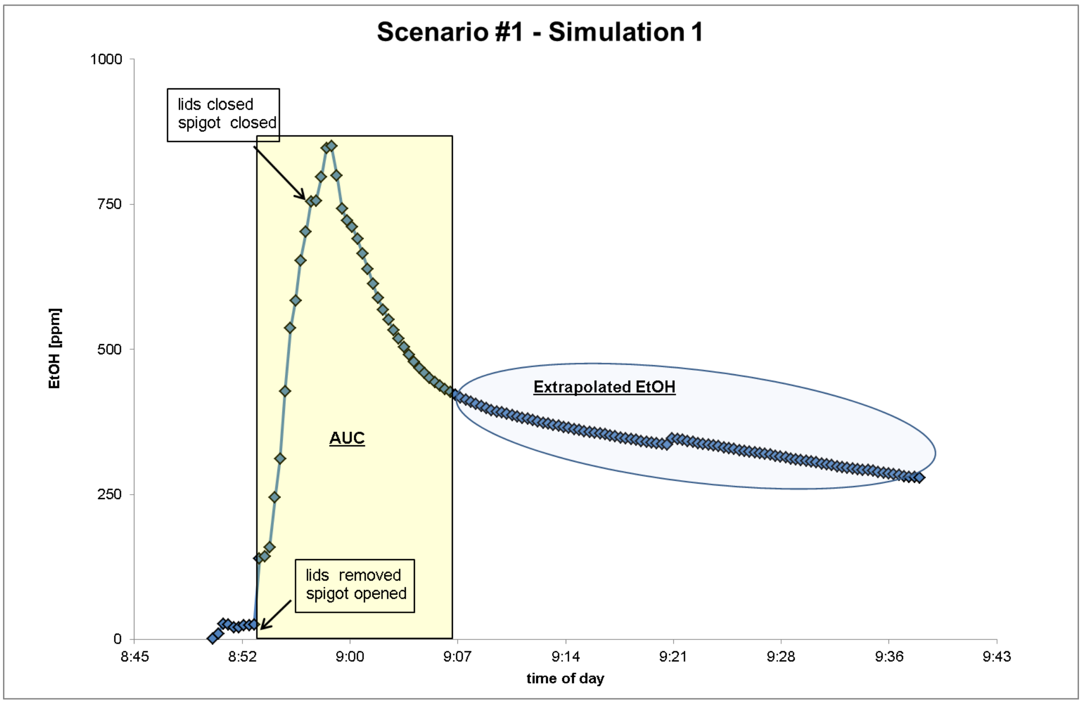

Fig. 2: Scenario #1; Simulation 1 – time of day vs ethanol concentration plot. Baseline – Gravity transfer from an open container into another open container with no exhaust and ventilation system in place. The yellow rectangle in the graph marks the time window considered for the calculation of the AUC (=measure for the total amount of ethanol measured at the sampling probe within that time window).

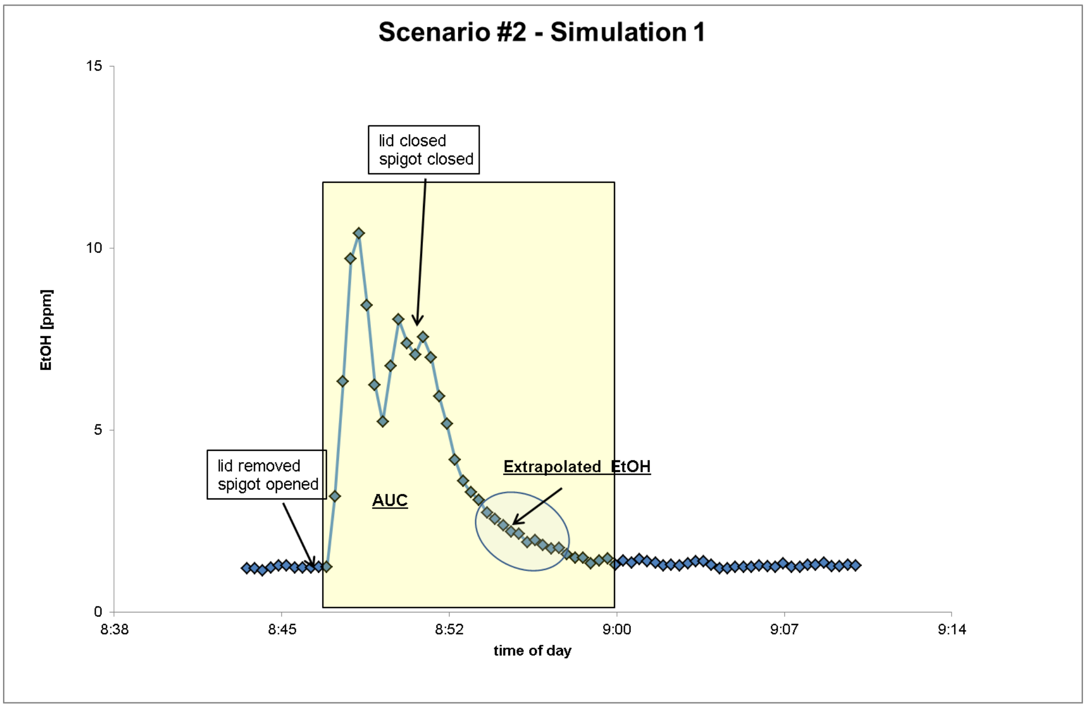

Fig. 3: Scenario #2; Simulation 1 – time of day vs ethanol concentration plot. Vented open gravity transfer with partial enclosure into a container within an operating 2-451-GAND fume hood. The yellow rectangle in the graph marks the time window considered for the calculation of the AUC (=measure for the total amount of ethanol measured at the sampling probe within that time window).

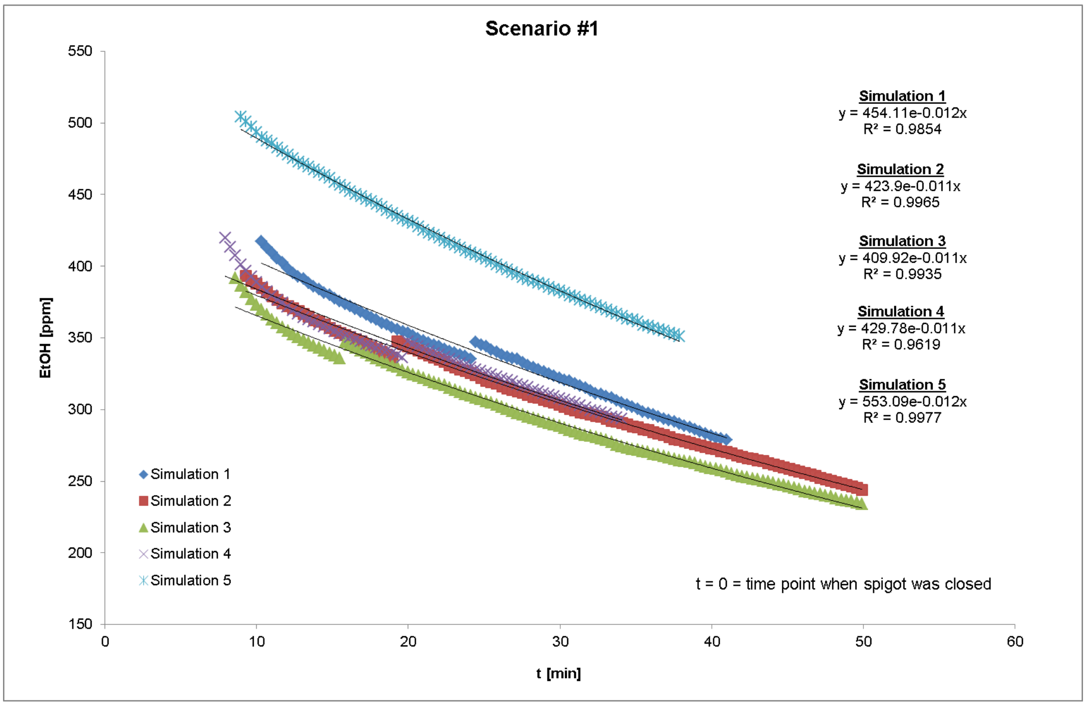

Fig. 4: Scenario #1 as example for simulations conducted with the room ventilation being switched off - Fitted data points for the determination of the extrapolated ethanol concentration. Trendline: $y = y_0 \exp(-kt)$; with y_0 being the extrapolated ethanol concentration and k*60 min being the air exchange rate.

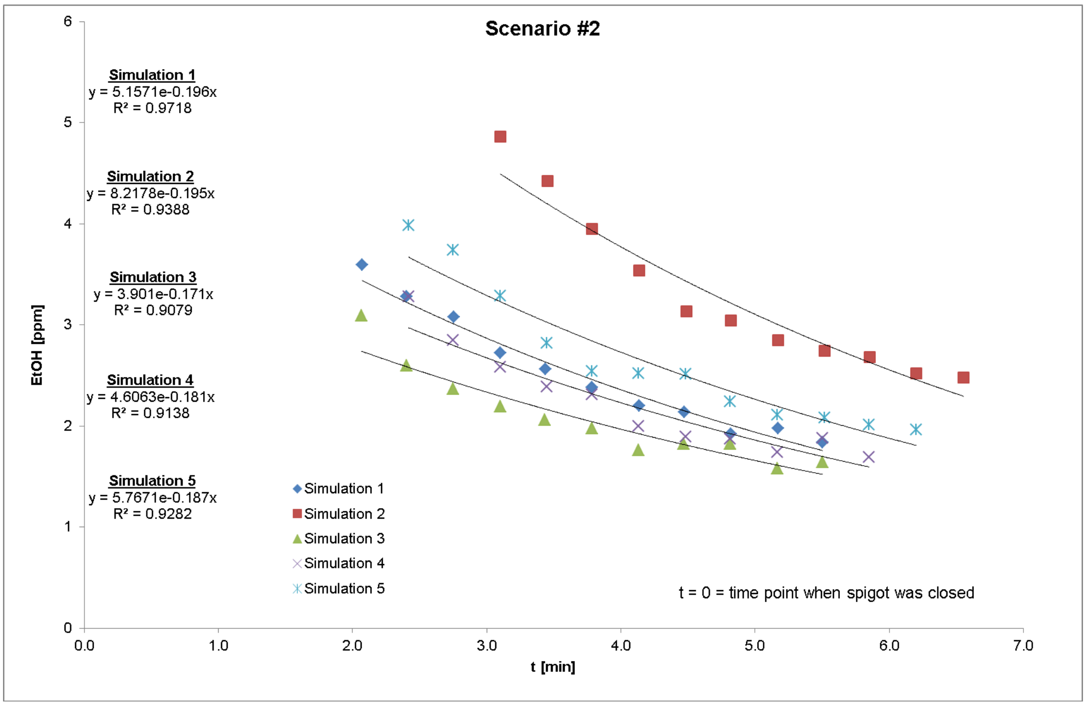

Fig. 5: Scenario #2 as example for simulations conducted with the room ventilation being switched on - Fitted data points for the determination of the extrapolated ethanol concentration. Trendline: $y = y_0 \exp(-kt)$; with y_0 being the extrapolated ethanol concentration and k*60 min being the air exchange rate.

4.2.4 Effectiveness

The effectiveness of the different RMMs was calculated using 1. peak ethanol concentrations, 2. area under the curve (measure for the total amount of ethanol measured at the sampling probe within a given time window of a simulation) and 3. extrapolated ethanol concentrations. The results are given in Table 26 to Table 30.
In general three values are given for the effectiveness of any given scenario within this study. They are calculated as follows:

1. Minimum observed exposure reduction in %: $(1-(E_{L,b} / E_{H,x}))*100$
2. Maximum observed exposure reduction in %: $(1-(E_{H,b} / E_{L,x}))*100$
3. Mean observed exposure reduction in %: $(1-(E_{M,b} / E_{M,x}))*100$.

$E_{L,b}$: *Lowest exposure value for baseline scenario*
$E_{H,b}$: *Highest exposure value for baseline scenario*
$E_{M,b}$: *Mean average exposure value for baseline scenario*
$E_{H,x}$: *Highest exposure value for scenario #X*
$E_{L,x}$: *Lowest exposure value for scenario #X*
$E_{M,x}$: *Mean average exposure value for scenario #X*

The minimum observed exposure reduction takes into account the simulation with lowest measured ethanol exposure in the baseline scenario and the simulation with the highest ethanol exposure for scenario #X.
The maximum observed exposure reduction takes into account the simulation with highest measured ethanol exposure in the baseline scenario and the simulation with the lowest ethanol exposure for scenario #X.
The mean effectiveness was calculated using the obtained mean values of the simulations for the respective scenarios.

An example for the calculated effectiveness values for the RMM[13] applied in scenario #2 (Vented open gravity transfer with partial enclosure) is given in Table 11. Thus the effectiveness of this RMM varies between 98.0 and 99.3 % and has a mean effectiveness of 98.8 %.

The assessment of the effectiveness of the different RMMs (**chapter 4.3**) will be based on the extrapolated ethanol data. The reasons behind this decision are detailed in **chapter 4.2.3**.

[13] Based on extrapolated ethanol concentrations.

Table 11: Effectiveness of RMM applied in scenario #2 compared to worst case baseline scenario #1.

Scenario #1	
Simulation #	**extrapol. EtOH [ppm]**
1	454
2	424
3	410
4	430
5	553
MV	**454**
STDEV	**51**
rel. STDEV [%]	**11**
Scenario #2	
Simulation #	**extrapol. EtOH [ppm]**
1	5
2	8
3	4
4	5
5	6
MV	**6**
STDEV	**1**
rel. STDEV [%]	**27**
Minimum observed exposure reduction [%]	**98.0**
Maximum observed exposure reduction [%]	**99.3**
Mean observered exposure reduction [%]	**98.8**

4.3 RESULTS

In the scope of this study the effectiveness of different RMMs in reducing solvent exposure during transfer was investigated. In order to assess their relative effectiveness (in %) a baseline scenario was set as reasonable worst case (scenario #1) to which all other gravity and selected drum pump transfer scenarios were compared to[14]. The average extrapolated ethanol concentration for the baseline was determined at 454 ppm (Table 12).

[14] The graphs depicting the ethanol exposure over the course of time for each simulation are shown in the appendix of this report (**Fig. A 3** to **Fig. A 45)**.

4.3.1 Gravity Transfer

The first three scenarios involving open gravity transfer were simulated applying three different RMMs. The effectiveness of a vented partial enclosure was studied in scenario #2. This scenario was simulated by moving the process of solvent transfer into a vented fume hood with the sash remaining fully open. The average extrapolated ethanol concentration presented with an average of 6 ppm a reduction of the ethanol exposure of 98.0 to 99.3 % (Table 12).

Upon turning scenario #2 into an open vented gravity transfer with full enclosure (scenario #3) the ethanol exposure was even further reduced to the point that no significant raise in the ethanol concentration over the course of the individual simulations was observed (example **Fig. 6**). Thus the effectiveness of the RMM simulated in scenario #3 is greater than 99.3 %.

Local containment of the entire process of solvent transfer into a vented fume hood-like place might not always be feasible. Local exhaust ventilation systems are conventional tools in reducing the solvent exposure by removing emitted fumes right at the source. A local exhaust ventilation system (LEV; "Elephant Trunk") was built by utilising the fume hood (scenario #4; **Fig. A 1D**). The effectiveness of this system was calculated to be between 96.5 – 97.9 % (Table 12). Interpretation of these values needs some caution since it was not possible during the experiments to test solely the impact of the LEV because the room ventilation could not be switched off[15] when the fume hood was operated. As a result part the effectiveness of the LEV may have been influenced by the active room ventilation. An additional set of exposure scenarios would be necessary, with the ability to shut off the room ventilation, to shed light onto this entanglement of RMMs.

First attempts to assess the contribution of the LEV to the effectiveness of this set of combined RMMs were made during the pilot study. First the effectiveness of room ventilation in conjunction with fume hood ventilation was determined as base configuration. In this configuration the LEV was assembled but made inoperative by covering its opening. In a second set of simulations the opening of the LEV was uncovered, allowing ethanol fume removal at the source. Comparing the latter to the base configuration showed a reduction in ethanol emission of 71.1 to 89.3 % (average: 81 %). Assuming a negligible interaction between the individual RMMs the observed average reduction in solvent emission of 81 % would be attributable to the LEV system alone. It would, however, require further experimental studies to prove this assumption.

[15] The inlet valve remained open, whereas the outlet was closed.

Table 12: Overview: Exposure reduction values for gravity transfer scenarios #2 to #4 compared to worst case scenario

Scenario #	1	2	3	4
Description	Baseline – Gravity transfer	Vented open gravity transfer with partial enclosure	Vented open gravity transfer with full enclosure	Gravity transfer – local exhaust system (room ventilation and fume hood switched on) and no enclosure
Simulation	**Extrapolated EtOH [ppm]**			
1	454	5	NoE	12
2	424	8	NoE	14
3	410	4	NoE	13
4	430	5	NoE	NA
5	553	6	NoE	NA
MV	**454**	**6**	**NoE**	**13**
	Exposure reduction			
Minimum [%]	NA	98.0	NA	96.5
Maximum [%]	NA	99.3	NA	97.9
Mean [%]	NA	98.8	NA	97.1

NoE - No observable increase in ethanol concentration in the room

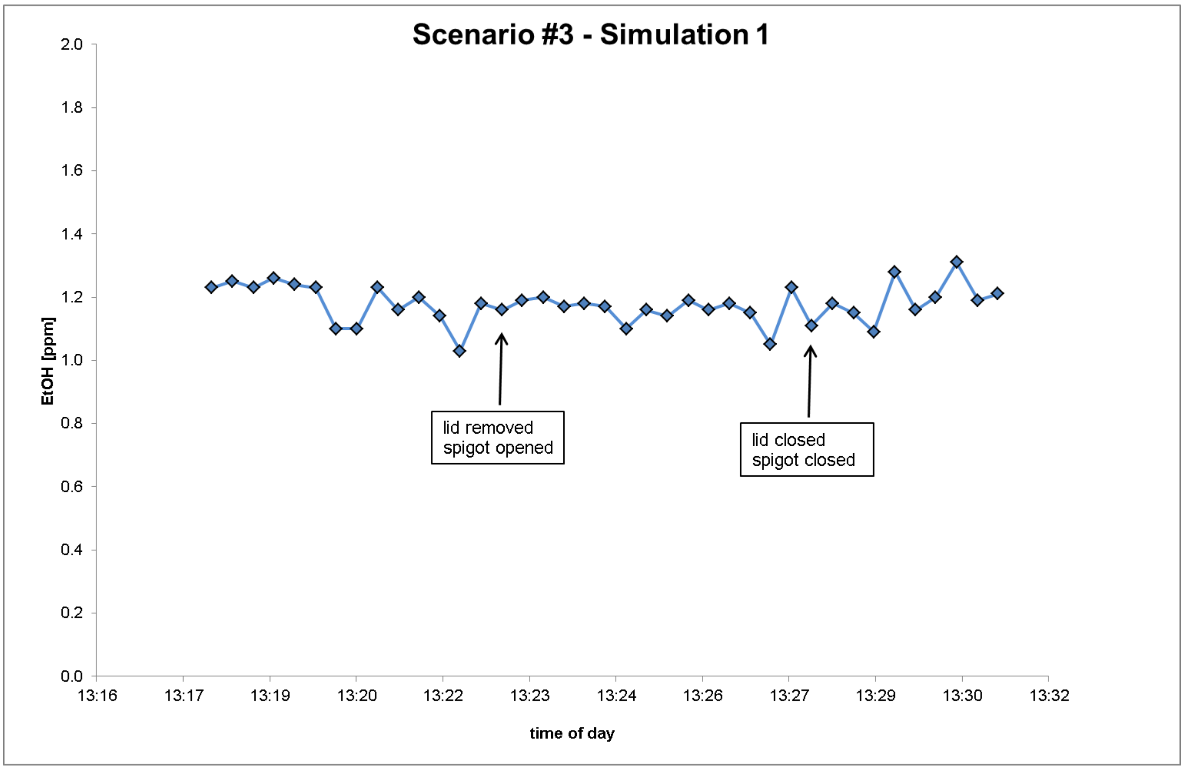

Fig. 6: Scenario #3; Simulation 1 – time of day vs ethanol concentration plot.

4.3.2 Drum pump transfer

The application of a drum pump was an effective RMM as it reduced the transfer time by a factor of approx. 6 when compared to the gravity transfer scenarios. In addition to this the drum pump transfer allowed submerged loading in contrast to splash loading during gravity transfer. These two points are considered to be the major factors in contributing to the exposure reduction during solvent transfer. A further factor influencing the effectiveness of the control is the size of the drum openings. For the gravity transfer the lids of the source and receiving drums had been removed so the transfer was ‘open’, whilst for the drum pump transfer they were significantly smaller and may be considered an additional RMM (**Fig. A 1** and **Fig. A 2**).
The drum pump equivalent to the worst case gravity transfer (scenario #1) was scenario #5, which was a drum pump transfer with no containment in form of a fume hood or such and no exhaust or room ventilation system in place. The average extrapolated ethanol concentration for scenario #5 was 29 ppm, which equals an exposure reduction of 91.9 to 95.2 %; compared to baseline scenario #1 (Table 13). These data seem to suggest, that the sole use of a drum pump without any exhaust or ventilation system in place does not have quite the same effectiveness as gravity transfer including partial or full enclosure in combination with an exhaust system (Table 12) in regards to exposure reduction.

Table 13: Exposure reduction values for drum pump transfer scenarios #5 and #6 in comparison to the worst case scenario #1.

Scenario #	1	5	6
Description	Baseline – Gravity transfer	Drum pump transfer - no exhaust and ventilation system in place	Vented (room ventilation and fume hood switched on) drum pump transfer – partial enclosure
Simulation	Extrapolated EtOH [ppm]		
1	454	33	3
2	424	27	2
3	410	28	2
4	430	NA	NA
5	553	NA	NA
MV	**454**	**29**	**2**
	Exposure reduction		
Minimum [%]	NA	91.9	99.3
Maximum [%]	NA	95.2	99.7
Mean [%]	NA	93.5	99.5

Vented drum pump transfer with partial enclosure[16] (scenario #6) resulted in an average extrapolated ethanol concentration of 2 ppm, which equals an exposure reduction of 99.3 to 99.7 % (Table 13). The overall effectiveness of the RMMs combined in scenario #6 puts it on a similar level in regards to exposure reduction as scenario #3 (vented open gravity transfer with full enclosure; Table 12). Comparing scenario #6 to the worst case drum pump scenario (#5) the incorporation of an exhaust system and a partially confined compartment yielded in an exposure reduction of 89.6 – 93.2 % (Table 17).

The effect of a local exhaust ventilation (LEV, "elephant trunk") was investigated for drum pump transfer (#7) as it was done for gravity transfer (#4). The comparison of ES5 and ES7 to the worst case scenario #1 showed that the exposure reduction efficiency of the drum pump (93.5 %) could be further increased to 98.9 % by the application of the assembled LEV[17] in combination with room ventilation (Table 14). As the extent of their interaction is not known a first attempt was made to disentangle the three RMMs (room ventilation, fume hood ventilation and LEV) by implementing scenario #7a. Here, the room ventilation and fume hood ventilation were switched on, but the LEV was made inoperative, by covering its entrance. This resulted in a decrease in exposure reduction from 98.9 % down to 96.6 % (Table 15).

In relation to the worst case drum pump scenario (#5) the application of a combination of RMMs as represented by scenario #7 constitutes an exposure reduction of 79.0 to 85.8 % (Table 14).

[16] This scenario was simulated by moving the process of solvent transfer into a vented fume hood with the sash remaining fully open.
[17] LEV could only be operated in conjunction with the fume hood.

Table 14: Exposure reduction values for LEV system and room ventilation (#7) in comparison to the two worst case scenarios #1 and #5.

Scenario #	1	5	7	
Description	Baseline – Gravity transfer	Drum pump transfer - no exhaust and ventilation system in place	Drum pump without enclosure , with LEV, fume cupboard and room ventilation in place – submerged loading	
Simulation	**Extrapolated EtOH [ppm]**			
1	454	33	5.6	
2	424	27	4.7	
3	410	28	4.9	
4	430	NA	NA	
5	553	NA	NA	
MV	**454**	**29**	**5**	
Exposure reduction compared to			**Scenario #1**	**Scenario #5**
Minimum [%]	NA	NA	98.6	79.0
Maximum [%]	NA	NA	99.1	85.8
Mean [%]	NA	NA	98.9	82.8

Table 15: Exposure reduction values for scenarios #7 and #7a in comparison to baseline scenario #1.

Scenario #	1	7	7a
Description	Baseline – Gravity transfer	Drum pump without enclosure, with LEV, fume cupboard and room ventilation in place – submerged loading	Drum pump without enclosure, without LEV, with fume cupboard and room ventilation in place – submerged loading
Simulation	**Extrapolated EtOH [ppm]**		
1	454	6	9
2	424	5	14
3	410	5	21
4	430	NA	19
5	553	NA	NA
MV	**454**	**5**	**16**
	Exposure reduction		
Minimal [%]	NA	98.6	94.9
Optimal [%]	NA	99.1	98.4
Mean [%]	NA	98.9	96.6

Note:

None of the drum pump scenarios presented here take into account the change over of the drum pump equipment after solvent transfer. This change over presents another source of solvent exposure not caused by the solvent transfer per se but by the drum pump. This is due to residual amounts of solvent on the drum pump parts which were in contact with the transferred solvent. Another relevant point is any residual volume of solvent contained within the drum pump which may be released upon equipment change over.

4.3.3 Drain and Flush Application

In order to assess the effectiveness of flushing a container on solvent exposure reduction it was necessary to establish the baseline of a just drained container (scenario #8). The latter was simulated by rinsing the inside of the collection container with 1x 5 L ethanol and recording the released ethanol fume over an arbitrary time window. The mean extrapolated ethanol concentration for this scenario was determined as 53 ppm. The scenario of a flushed container (scenario #9) was simulated by rinsing the inside of the collection container with 5 L ethanol followed by two rinses with 10 L water. The course of the recorded ethanol exposure course for this scenario (example **Fig. 7**) did not allow the determination of an extrapolated ethanol concentration. Hence, the exposure concentration was calculated as average concentration of all recorded data points between opening and closing the lid of the flushed container (Table 16). The effectiveness of reducing solvent exposure by rinsing a just drained container was determined as 93.2 to 96.6 % (Table 16).

Table 16: Effectiveness of flushing container on exposure reduction.

Scenario #	8	9
Description	Base Configuration for scenario 9 - Drained container without flushing with no exhaust and ventilation system in place	Flushed container with no exhaust and ventilation system in place
Simulation	**Extrapolated EtOH [ppm]**	**Mean* EtOH [ppm]**
1	59	2.5
2	54	3.1
3	46	2.0
MV	**53**	**2.5**
	Exposure reduction	
Minimum [%]	NA	93.2
Maximum [%]	NA	96.6
Mean [%]	NA	95.2

* Average of all concentration data points between opening and closing lid

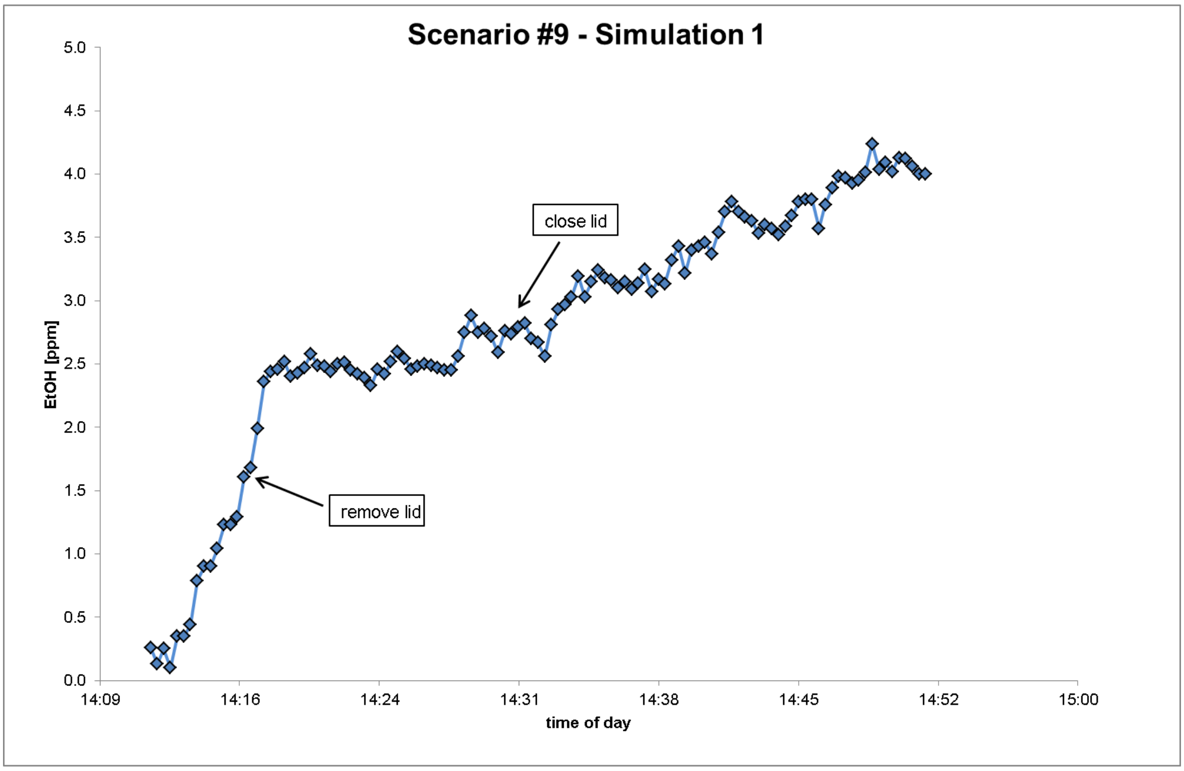

Fig. 7: Scenario #9; Simulation 1 – time of day vs ethanol concentration plot.

5 DISCUSSION

This report describes the evaluation of risk management measures used to control solvent vapour emission. In the first part of the project publications and other publically available information on RMMs in the solvent industry was gathered. However, in the course of the investigation and interviews it was found that the efficacy of exposure controls is not systematically studied or publicized. Although a number of search hits for solvent exposure data can be found in the open literature specific information for assessing exposure reduction efficiency in most cases is insufficient as detailed contextual information is seldom recorded or the corresponding information does not refer to solvents and related tasks (e.g. Fransman et al. [11]).

Concerning the evaluated RMMs (see section 2) only exposure reduction values for different levels of containment and ventilation were identified and only for selected areas (health care / agriculture / experimental studies) the suggested efficiencies are supported by published information. Overall the exposure reduction efficiencies found in literature for different levels of containment and industry areas range from 14% (manufacture of automotive parts / type of setting unknown) to 94% (agriculture / professional, see Table 7) and seem to depend heavily on various factors such as age of data, industry area, the evaluated process and operational conditions, good practice and the substance handled. None of the efficiencies found in literature represents the transfer of solvents. Thus, it was decided to further evaluate the influence of RMMs on inhalation exposure via experimental studies.

Laboratory based simulations enabled investigators to gather necessary empirical data to assess exposure conditions with and without risk management measures.
Experimental results presented in Table 17 appear to support exposure reduction efficiencies proposed by ESIG exposure science experts. Mean exposure reductions were generally high above 90% for most tested (combinations of) risk management measures and are overall consistent with the values suggested by ESIG and ECETOC TRA. The following points can be summarised:

- LEV shows around 97% efficiency in combination with present room ventilation. This is similar to most ECETOC TRA defaults (75-95% for LEV depending on PROC, 30 or 70% for general room ventilation resulting in ~83-98.5% for overall ventilation). The values measured in the course of this study are partly consistent with values previously collected by Fransman et al. [11] (82% average for LEV overall (95% confidence interval 78-84), 64% for vapour collection (95% confidence interval 23-83%), very limited overlap of database with solvent scenarios).
- Full containment (closed fume cupboard with ventilation switched on) shows above 99% exposure reduction. This is consistent with a suggestion of 90 or 95% efficiency for E61 (full enclosure). This is not consistent with data identified during the literature review (71-91%, limited overlap of database with solvent scenarios)
- Partial containment (open fume cupboard with ventilation switched on) leads to 93.3-98.8% exposure reduction (drum pump transfer and open gravity transfer). This is consistent with an ESIG suggestion of 80 or 90% for E60 (partial enclosure). This is not consistent with data identified during the literature review (14-90%, limited overlap of database with solvent scenarios)
- The use of drum pumps with closed container lids for transfer leads to a reduction of 93.5%. This is consistent with an ESIG suggestion of 80% for E53 (use of drum pumps) or E68 (restricted area of openings). Both measures together would require an efficiency of 96% based on ESIG defaults (based on multiplication of factors). However, since the restriction of openings, i.e. closed lids, is a standard procedure for filling of volatile solvents it may be debatable to which extent this experiment should be seen as an evaluation of E68 and E53 in combination or rather an evaluation of appropriate drum pump use which incidentally includes the restriction of openings.

- Flushing of a drum before opening leads to a reduction of 95.2%. This is consistent with an ESIG suggestion of 90% for E55 (draining and flushing). The draining aspect of this measure has not been evaluated. However, it is considered to be unlikely that draining will lead to higher exposures in reality. Thus, the estimated efficiency represents a worst case.

Several combinations of measures have been evaluated as well and show reasonably high exposure reductions. However, from the experiments no conclusion is possible if a multiplication of efficiencies as implemented as an example in ECETOC TRA is also reflected in reality.

Some scenarios within the project included general room ventilation due to technical requirements. Proper operation of the fume hood in the room was only constituted when the room ventilation was switched on. The contribution of the room ventilation was regarded as negligible when exposure scenarios involving solvent transfer inside the operating fume hood were investigated. First attempts were made to evaluate the corresponding efficiency of room ventilation alone or as additional measure. However, possible interactions among the individual RMMs could not be ruled out. Hence, no individual exposure reduction values were assigned for room ventilation and LEV. Further research will be needed in order to shed light on possible interactions between individual RMMs.
Comparing the combined effect of LEV and room ventilation observed in the laboratory study with the respective ECETOC TRA output similar reduction values were found.
In order to avoid any ambiguity regarding data evaluation, operating room ventilation is documented for all affected exposure scenarios (in Table 1 and Table 17).

Although exposure measurements were collected under controlled experimental conditions, the data together with qualitative information gathered from field interviews support exposure reductions comparable to ESIG suggestions can be achieved. However, appropriate handling (good practice) and comparable conditions are necessary in order to ensure comparable results.
Available experiments do not consider any other activities such as equipment change over that might also pose a source of solvent exposure. For example, in case of the drum pump scenarios only the filling itself was evaluated. But while exposure during the actual use of a drum pump is very low, peaks of exposure may occur during removal of the pump or change to the next drum.
Further uncertainties might originate from changes within the room such as, movements within the room or the position of the sampling probe. However, these uncertainties mostly influence the peak concentrations and AUC and could be compensated by using extrapolated ethanol concentrations for the calculation of efficiency values which are less affected as the data points considered for the calculations are recorded after distribution of the ethanol fumes around the sampling probe.

A key parameter in assessing RMM efficiency is the choice of the scenario conditions used for comparison. As a worst case baseline scenario, mostly ES1 has been used for comparison purposes. However, depending on the evaluated measure other comparisons are possible. As an example, ES6 can be compared with ES1 (phrase E66, E68, E53) or with ES5 providing some insight in the additive effect of working under containment or extract ventilation (E66) in combination with drum pump use. In general the temperature and ventilation conditions present during the experiment are expected to be sufficiently comparable to operating conditions present in actual work settings or assumed in the ECETOC TRA model, e.g. transfer without exhaust and ventilation system (see Table 17 for details).

This study did not differentiate the type of setting (professional / industrial). Laboratory environments may be very similar regardless of whether they are present in an industrial complex or other professional setting. However, transfer processes and the evaluated measures in general are not limited to laboratory environments. Thus, it may be important to further examine whether solvent transfer tasks carried out in industrial environments differ at all from solvent transfer tasks by professionals in other work settings.

Of the phrases originally selected two were not directly evaluated, E68 and “E65 or E81”.
For E68, “restrict area of openings to equipment”, an exposure reduction efficiency of 80% had been suggested by ESIG. Although this value cannot be confirmed by a separate experimental study, related experiments for partial and full enclosure suggest that it may be reasonable, considering the fact that very high exposure reductions, partly above 99%, could be achieved by both experiments. Furthermore, results obtained during use of a drum pump (E53, restriction of openings included in scenario as closed lids are standard for drums with solvents), indicate similar results (93.5%).
For E65 or E81 (“Drain down system prior to equipment break-in or maintenance” or “Drain or remove substance from equipment prior to break-in or maintenance”) also 80% exposure reduction had been suggested. Potentially the drain and flush simulation (E55), which demonstrated a significant exposure reduction and thereby a high effectiveness of this RMM (above 90%) in the experimental part of this project (chapter 4.3.3) could be used as a comparison for “E65 or E81”. However, the scenario used as a base configuration in this case consists of an already drained drum, i.e. the relevant aspect is not included.
The phrase “E65 or E81” may be even more difficult to verify experimentally since in reality parts of equipment will not consist of simple drums with solvent. Increased risks of spilling will be possible if non-drained equipment is opened (→ baseline scenario) and it may be questionable if an open ethanol drum can be considered to be representative in this case. Due to the large, wet surface a drained but not flushed drum may even lead to higher exposure than a full one and it is not known to which extent this applies to other pieces of equipment. A conclusion concerning likely exposure reductions is therefore not possible at this point for drain and flush control measures.

Overall it can be summarised that the experimental results are consistent with the suggested exposure reduction values for all types of commonly encountered exposure control (and their associated phrases). For scenarios where combinations of measures have been evaluated care has to be taken in order to assign the correct phrases to the corresponding exposure reduction.
Two phrases, E68 and “E65 or E81”, have not been evaluated experimentally directly. However, while for E68 (restrict area of openings to equipment) it seems likely that the suggested value is reasonable, no conclusion for “E65 or E81” (Drain down system prior to equipment break-in or maintenance or Drain or remove substance from equipment prior to break-in or maintenance) is possible.

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6 CONCLUSION

In this project, information about exposure reductions resulting from the application of different forms of risk management measures used in the solvent industry has been gathered via review of literature and available information from industry and other organisations.
Since the available published information was limited, it has been supplemented by experimental studies (see Table 17). It can be concluded that, although the experimental studies have some limitations, the expectations concerning their ability to describe exposure reduction potential were met. Partial and vented containment, full and vented containment and the use of drum pumps with closed container lids for transfer activities all lead to exposure reductions above 90%. Thus, drum pumps are a suitable alternative to LEV systems for solvent transfer activities.
All of the RMM studies showed an effectiveness greater than 90 % and many show an effectiveness of >95%. Thus the investigated studies demonstrate that suitable ways exist to reduce exposure at workplaces where solvents are handled.

Table 17: Experimental results and comparison with suggestions originally used in chemical safety assessments.

				exposure reduction (%)			
Evaluated ES #	**ES # for comparison**	**experimental aspect represented by exposure reduction**	**Phrase(s) represented by exposure reduction:**	**Minimal**	**Optimal**	**Mean**	**efficiency originally suggested by ESIG and TRA (%)**
Gravity transfer							
2: Vented open gravity transfer with partial enclosure (inside open fume cupboard, switched on) into a container, room ventilation	1: Baseline – Gravity transfer from an open container into another open container with no exhaust and no room ventilation system in place	Open fume cupboard (switched on), room ventilation	E60 'Minimise exposure by partial enclosure of the operation or equipment and provide extract ventilation at openings' General room ventilation	98	99.3	98.8	E60: 80 (prof) /90 (industrial)
3: Vented open gravity transfer with full enclosure (inside closed fume cupboard, switched on) into a container, room ventilation	1: Baseline – Gravity transfer from an open container into another open container with no exhaust and no room ventilation system in place	Closed fume cupboard (switched on), general room ventilation	E61 Minimise exposure by extracted full enclosure for the operation or equipment General room ventilation	>99	>99	>99	E61: 90 (prof) /95 (industrial)
4: Gravity transfer from an open container into another open container – application of a local exhaust system (LEV, elephant trunk) and no enclosure (outside fume cupboard)[18], with room ventilation	1: Baseline – Gravity transfer from an open container into another open container with no exhaust and no room ventilation system in place	LEV+room ventilation	E54 'Provide extract ventilation to points where emissions occur'; or E66 'Ensure material transfers are under containment or extract ventilation' General room ventilation	96.5	97.9	97.1	general ventilation: 30 / 70 (good / enhanced; standard ECETOC TRA efficiency) LEV: 75-95 (in general); 80-95 (PROC8a/8b/9) (standard ECETOC TRA efficiency)
Drum pump transfer							
5: Drum pump transfer (closed lids) with no exhaust and no room ventilation system in place – accurate use of drum pump (submerged loading),	1: Baseline – Gravity transfer from an open container into another open container with no exhaust and no room ventilation system in place	Drum pump; (closed container lids – standard for solvent drum transfer)	E53 ' Use of drum pump' (E68: Restrict area of openings to equipment)	91.9	95.2	93.5	E53 (E68): 80 (all uses)

[18] LEV efficiency probably lower, 14 - 16.5 % room ventilation efficiency included.

				exposure reduction (%)			
Evaluated ES #	**ES # for comparison**	**experimental aspect represented by exposure reduction**	**Phrase(s) represented by exposure reduction:**	**Minimal**	**Optimal**	**Mean**	**efficiency originally suggested by ESIG and TRA (%)**
6: Vented drum pump transfer (closed lids) with partial enclosure (inside open fume cupboard, switched on) – accurate use of drum pump (submerged loading) , room ventilation	1: Baseline – Gravity transfer from an open container into another open container with no exhaust and no room ventilation system in place	Drum pump; (closed container lids – standard for solvent drum transfer); open fume cupboard (switched on), general room ventilation	E53 ' Use of drum pump' (E68, 'Restrict area of openings to equipment') and E66 'Ensure material transfers are under containment or extract ventilation.'	99.3	99.7	99.5	E53 (E68): 80 (all uses)
6: Vented drum pump transfer (closed lids) with partial enclosure (inside open fume cupboard) – accurate use of drum pump (submerged loading), room ventilation	5: Drum pump transfer (closed lids) with no exhaust and no room ventilation system in place – accurate use of drum pump (submerged loading)	Open fume cupboard (switched on)	E66 'Ensure material transfers are under containment or extract ventilation.'	89.6	93.2	93.1	E60: 80 (prof) /90 (industrial)
7a: Drum pump (closed lids), no enclosure (outside fume cupboard), with room ventilation, but no local exhaust system in place – accurate use of drum pump (submerged loading) [18]	1: Baseline – Gravity transfer from an open container into another open container with no exhaust and no room ventilation system in place	Drum pump, (closed container lids – standard for solvent drum transfer), general room ventilation	E53 ' Use of drum pump' (E68: Restrict area of openings to equipment General room ventilation)	96.2	97.8	96.4	E53/ E68: 80 (all uses) general ventilation: 30 / 70 (good / enhanced; standard ECETOC TRA efficiency)
7: Drum pump (closed lids) without enclosure (outside closed fume cupboard), with room ventilation and a local exhaust ventilation system (elephant trunk) in place – accurate use of drum pump (submerged loading) [18]	1: Baseline – Gravity transfer from an open container into another open container with no exhaust and no room ventilation system in place	LEV+general room ventilation + drum pump (closed container lids – standard for solvent drum transfer)	E54 'Provide extract ventilation to points where emissions occur' Or E66 'Ensure material transfers are under containment or extract ventilation.' and E53 ' Use of drum pump' (E68, 'Restrict area of	98.6	99.1	98.9	general ventilation: 30 / 70 (good / enhanced; standard ECETOC TRA efficiency) LEV: 75-95 (in general); 80-95 (PROC8a/8b/9) (standard ECETOC TRA efficiency)

				exposure reduction (%)			
Evaluated ES #	**ES # for comparison**	**experimental aspect represented by exposure reduction**	**Phrase(s) represented by exposure reduction:**	**Minimal**	**Optimal**	**Mean**	**efficiency originally suggested by ESIG and TRA (%)**
			openings to equipment' General room ventilation)				
7: Drum pump (closed lids) without enclosure (outside closed fume cupboard,), with room ventilation and a local exhaust ventilation system (elephant trunk) in place – accurate use of drum pump (submerged loading) [18]	5: Drum pump transfer (closed lids) with no exhaust and no room ventilation system in place – accurate use of drum pump (submerged loading)	LEV + general room ventilation	E54 'Provide extract ventilation to points where emissions occur' or E66 'Ensure material transfers are under containment or extract ventilation.' and General room ventilation	79	85.8	82.8	general ventilation: 30 / 70 (good / enhanced; standard ECETOC TRA efficiency)
Flushing and draining							
9: Flushed container with no exhaust system and no room ventilation in place	8: Drained container without flushing with no exhaust system and no room ventilation in place	Working on flushed equipment	E55 'Drain down and flush system prior to equipment break-in or maintenance.'	93.2	96.6	95.2	E55: 90 (industrial)
			E65 'Drain down system prior to equipment break-in or maintenance.' or E81: Drain or remove substance from equipment prior to break-in or maintenance.				E65 or E81: 80 (all uses)

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LIST OF FIGURES

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APPENDIX A: DRUM PUMP MANUFACTURERS

LIST OF DRUM PUMP MANUFACTURERS: GERMANY

	Company	Adress	Contact data	Webpage
1	JESSBERGER GmbH	Jägerweg 5	Phone: +49 (0)89 – 66 66 33 400	http://www.fasspumpe.com/
		D-85521 Ottobrunn	Fax: +49 (0)89 – 66 66 33 411	
			info@jesspumpen.de	
2	Lutz Pumpen GmbH	*Administration*	Tel.: +49 (0)9342 8 79-0	www.lutz-pumpen.de
		Erlenstrasse 5-7	Fax: +49 (0)9342 87 94 04	
		Production	info@lutz-pumpen.de	
		Am Stammholz 11		
		DE-97877 Wertheim		
		Other sites in USA, UK, NL, HU, AT, CN		
3	FLUX-GERÄTE GMBH	Talweg 12	Phone: +49 (0) 70 43 / 101 - 0	http://www.flux-pumpen.de/en/contact.html
		75433 Maulbronn	Fax national: +49 (0) 70 43 / 101 - 444	
			Fax international: +49 (0) 70 43 / 101 - 555	
			info@flux-pumpen.de	
4	Bürkle GmbH	Rheinauenstraße 5	+49 (0) 7635 / 82795–0	http://www.buerkle.de/de/shop/_fasspumpen.html
		79415 Bad Bellingen	info@buerkle.de	
			Head of research and development: Michael Greiner Tel: +49 (0) 7635 82795-44	
5	Betz Technologies GmbH	Am Obereichholz 4	Phone: + 49 (0) 9391 98 26 0	http://www.betz-technologies.de/de/produkte/hydraulische-und-

				pneumatische-kolbenhubpumpen/fasspumpen/
	(Drum pumps especially designed for offset inks)	97828 Marktheidenfeld	Fax: +49 (0) 9391 98 26 50	
			info@betz-technologies.de	
6	DELLMECO	Industriestraße-West 1	Phone: (+49)06021 4463980	http://dellmeco-deutschland.de/produkte/doppelmembranpumpen/membranfasspumpendetails.html
	Deutschland GmbH	D-63808 Haibach	Fax: (+49)06021 4463985	http://dellmeco-deutschland.de/english/index.php
			eMail: info@dellmeco.net	
7	KEWESTA GmbH	Industriestraße 2-6	Phone: +49 (0) 6183-9168-0	http://www.kewesta.de/de/antriebstechnik/airmover/fasspumpen/
		D-63526 Erlensee	Fax: +49 (0) 6183-9168-66	http://www.kewesta.de/kontakt/
			eMail: info@kewesta.de	
8	ZUWA-Zumpe GmbH	Franz-Fuchs-Straße 13 - 17	Tel: +49 (0) 8682 / 8934-0	http://www.zuwa.de/pumpen/fasspumpe.htm
	(Barrel pump for Oil and Diesel)	D-83410 Laufen	eMail: info@zuwa.de	
9	NETZSCH Pumpen & Systeme GmbH	Geretsrieder Straße 1	Tel.: (+49) 8638 63-0	http://www.netzsch-pumpen.de/de/produkte-loesungen/dosieren-und-entleeren.html
		84478 Waldkraiburg	Fax: (+49) 8638 67981	
		Deutschland	info.nps@netzsch.com	
10	UMETA Hermann Ulrichskötter	Almestraße 1-3	Phone: +49 (0)521.948-0	http://www.umeta.com/en/home/produkte/druckfettpressen/handlever-oil-barrel-pump.html
	Metallwarenfabrik GmbH & Co. KG	33649 Bielefeld	Fax: +49 (0)521.948-111	UMETA Handlever Oil Barrel Pump (steel tube)
			eMail: info@umeta.com	
11	Polycraft GmbH	Messenhäuser Str. 32	Phone: +49 6074 4818188	www.polycraft.de
	(distributor in Europe for IPM, Drum pumps supply Resin or ISO from 55 gal. or IBC containers to the proportioner.)	63322 Rödermark	Fax: +49 6074 4818151	www.polycraftusa.com
			Mobile: +49 171 5169860	http://www.polycraft.de/php/fasspumpenundfassmaterial.php
			eMail: info@polycraft.de	

			eMail: info@polycraftusa.com	
12	Samoa-Hallbauer GmbH	Industriestraße 18	Phone +49 62 04/70 95-0	http://samoa-hallbauer.de/branchen/chemie.html
		D-68519 Viernheim	Fax +49 62 04/70 95-33	
			eMail: info@samoa-hallbauer.de	
13	Pumpenfabrik Wangen GmbH	Simoniusstrasse 17	Tel: +49 7522 997-0	http://www.wangen.com/anwendungen/anwendungen.html
		D-88239 Wangen	Fax: +49 7522 997-108	
			eMail: mail@wangen.com	
14	KNOLL Maschinenbau GmbH	Schwarzachstraße 20	+49 (0) 7581/2008-130	http://www.knoll-mb.de/de/pumpen/produkte.html
	(cooling lubricants)	D-88348 Bad Saulgau	+49 (0) 7581/2008-332	
15	grün-pumpen GmbH	Otto-Schott-Strasse 19	Phone: +49 (0) 93 42 - 9 35 16-0	http://www.gruen-pumpen.de/
		D-97877 Wertheim	Fax: +49 (0) 93 42 - 9 35 16-29	
			eMail: info@gruen-pumpen.de	
16	COMET - Pumpen	Industriestraße 5	Tel: ++49 (0) 36082 436-0	http://www.comet-pumpen.de/index.php?id=42&L=1
	Systemtechnik GmbH & Co. KG	D - 37308 Pfaffschwende	Fax: ++49 (0) 36082 43634	
			contact(at)comet-pumpen.de	
17	MARCH PUMPEN GmbH	Rathenaustraße 2	Phone: +49/(0)641/68 68 06 -0	http://www.march-pumpen.com
		D-35394 Gießen/Hessen	Fax: +49/(0)641/68 68 06 - 60	
			eMail: info@march-pumpen.com	
18	M+B Fluid Technology GmbH	Dietrich Bonhoeffer Strasse 21	Phone: 06421-6209440	https://www.mb-fluid.de/handpumpen/
		D-35037 Marburg	Fax: 06421-6209441	

			eMail: kontakt@mb-fluid.de	

LIST OF DRUM PUMP MANUFACTURERS: INTERNATIONAL

	Company	Adress	Contact data	Webpage
1	AQUASYSTEM Co.,Ltd.	1-3-1 Kyo-machi	http://www.aqsys.co.jp/english/	http://www.hannovermesse.de/product/air-presser-drum-pump-apd-20ex/427416/B895009
		Hikone-city	Phone: +81 749 23 9123	
		Japan	Fax: +81 749 23 9122	
			eMail: aqua@aqsys.co.jp	
2	IPM USA	3107 142nd Avenue East #106 Sumner,	Phone: (1) 253 863 2222	http://www.ipmpumps.com/
	International Pump Manufacturing, Inc	WA 98390	Fax: (1) 253 863 2223	
			eMail: sales@ipmpumps.com	
3	KIJEKA ENGINEERS PRIVATE LIMITED 404, 4th floor, "ANUSHRI",	Near Bank of Baroda,	Phone: +91-79-2755 0248.	http://www.kijeka.com/pumps.html
		Ashram Road, Usmanpura,	Fax:+91-79-4007 0248.	
		AHMEDABAD - 380 013,	Mobile: From India 0-98795 45352	
		Gujarat State,	From Anywhere in the world: +91-98795 45352	
		India.	eMail: For informationinfo@kijeka.com	
			eMail:For overseas inquiriesoverseas@kijeka.com	
			eMail:For technical helphelp@kijeka.com	
4	SAVINO BARBERA SRL	12, v. Torino	Phone: +30 011 9139063	http://www.chemikalienpumpen.de/prodotti/pompe-per-fusti-e-barili
		I-10032 Brandizzo (TO)	Fax: +39 011 9137313	
			eMail: info@savinobarbera.com	
			www.savinobarbera.com	
5	Pompe Casali S.r.l.	Via Lazzari 1	Tel + +39 051 76.76.05	http://www.pompecasali.it/eng/pages/contacts.html
		40057 Quarto Inferiore (Bologna) (Italy)	Commercial Department Fax +39 051 76.86.22	

			Administrative Department Fax +39 051 76.72.81	
			Technical Department Fax +39 051 60.58.689	
			eMail: info@pompecasali.it	

APPENDIX B: EXPOSURE REDUCTION VALUES FROM ECEL AND OTHER PUBLICLY AVAILABLE SOURCES OF INFORMATION

This table represents an excerpt from a more detailed Excel database that has been developed in the course of the project. More details can be found in the original Excel file.

Table 18: Dermal studies

industry	risk management strategy		task	substance	study	efficacy	average	source[19]	original publication	comment	compared situations	sampling type (personal /static)
E60 (professional and industrial)												
Rubber industry	Local exhaust ventilation	no enclosure specified	diverse (compounding, moulding, curing, finishing etc.)	Dermal exposure (cyclohexane soluble matters)	Intervention	0.68	0.68	literature search	Trends in exposure to inhalable particulate and dermal contamination in the rubber manufacturing industry: effectiveness of control measures implemented over a nine-year period; Vermeulen et al., Am. occup. Hyg. Vol. 44, NO5, pp 343-354, 2000 [32]	also other influences described but nothing directly related to ESIG RMMs. Anova modelling	with vs. without LEV	P

Table 19: Inhalation studies

industry	risk management strategy	task	substance	study	efficacy	average	source[19]	original publication	comment	compared situations	sampling[20]
E60 (professional)											

[19] If „ECEL“ is indicated, original publication was not evaluated in detail.
[20] P: personal; S: stationary

construction	Containment/Enclosure - no extraction; General ventilation	Partial containment (process intergrated); Mechanical ventilation using fan (dilution)	Paving	Naphthalene (fume)	Cross-sectional (a-priori design)	0.41	0.22	ECEL	Burstyn I, Randem B, Lien JE, Langard S, Kromhout H. Bitumen, polycyclic aromatic hydrocarbons and vehicle exhaust: exposure levels and controls among Norwegian asphalt workers. Ann Occup Hyg 2002; 46:79–87. (©Oxford University Press). [13]	Fume, but scenario more or less fitting, fume = small particles, i.e. probably similar to solvents	Paving machine equipped with fan and ventilated tarpaulin covering the screed vs. no control measures.	P
construction	Containment/Enclosure - no extraction; General ventilation	Partial containment (process intergrated); Mechanical ventilation using fan (dilution)	Paving	Bitumen (petroleum) (fume)	Cross-sectional (a-priori design)	0.04		ECEL	Burstyn I, Randem B, Lien JE, Langard S, Kromhout H. Bitumen, polycyclic aromatic hydrocarbons and vehicle exhaust: exposure levels and controls among Norwegian asphalt workers. Ann Occup Hyg 2002; 46:79–87. (©Oxford University Press). [13]	Fume, but scenario more or less fitting, fume = small particles, i.e. probably similar to solvents	Paving machine equipped with fan and ventilated tarpaulin covering the screed vs. no control measures.	P
construction	Containment/Enclosure - no extraction; General ventilation	Partial containment (process intergrated); Mechanical ventilation using fan (dilution)	Paving	Organic vapour (fume)	cross-sectional (a-priori design)	0.22		ECEL	Burstyn I, Randem B, Lien JE, Langard S, Kromhout H. Bitumen, polycyclic aromatic hydrocarbons and vehicle exhaust: exposure levels and controls among Norwegian asphalt workers. Ann Occup Hyg 2002; 46:79–87. (©Oxford University Press). [13]	Fume, but scenario more or less fitting, fume = small particles, i.e. probably similar to solvents	Paving machine equipped with fan and ventilated tarpaulin covering the screed vs. no control measures.	P
E60 (industrial)												

Metal / metallurgical industry	Source segregation	Partial segregation with air supply ventilation / filtered recirculated air	Machining	Total particulate	Intervention	0.27	0.27	ECEL	Yacher et al., Mist control at machining centers part 2 - mist control following installation of air cleaners, AIHAJ, vol 61, p282, 2000 [14]	not mwf measured	Metalworking stations without enclosure and exhaust ventilation vs. Metalworking stations with (nearly complete) enclosure and air filter unit (model F120 (1.13 m3/sec))	P
E60 (professional+industrial)												
Metal / metallurgical industry	Containment/ Enclosure - no extraction; Local ventilation systems - Enclosing hoods	Low-level containment; Other enclosing hoods	Machining	Metal working fluids (MWF)	Cross-sectional (a-posteriori design)	0.94	0.47	ECEL	Hands D, Sheehan MJ, Wong B, et al. Comparison of metalworking fluid mist exposures from machining with different levels of machine enclosure. Am Ind Hyg Assoc J. 1996;57:1173–8. [15]	Fume, but scenario more or less fitting, fume = small particles, i.e. probably similar to solvents	No or minimal enclosure (e.g. splash guarding) vs Retrofit enclosures (defined as either partial enclosures installed when the machine was new, or partial or total enclosures fabricated after the machinery was designed and installed; most of these enclosures were equipped with local exhaust)	P

Metal / metallurgical industry	Containment / Ventilation	partial enclosure + ventilation	Grinding	total dust	Intervention	0.41		literature search	Control of exposure to cobalt during grinding of hard metal blades, Linnainmaa, appl. occup. environ. hyg. vol.1, no.8, p692, 1995 [16]	workplace C, dust measured but workplace also includes mwf, therefore maybe useful anyway	semi-automatic machines splash guard without exhaust vs. new splash guards, full enclosure, ducts and fan not changed AND for manual machine splash guard and LEV vs. partial enclosure, ducts and fan not changed	s
Metal / metallurgical industry	Containment / Ventilation	partial enclosure + ventilation	Grinding	cobalt exposure	Intervention	0.15		literature search	Control of exposure to cobalt during grinding of hard metal blades, Linnainmaa, appl. occup. environ. hyg. vol.1, no.8, p692, 1995 [16]	workplace C, content of water soluble cobalt in overall exposure is high	semi-automatic machines splash guard without exhaust vs. new splash guards, full enclosure, ducts and fan not changed AND for manual machine splash guard and LEV vs. partial enclosure, ducts and fan not changed	s

Metal / metallurgical industry	Containment / Ventilation	partial enclosure + ventilation	Grinding	cobalt (in urine)	Intervention	0.36		literature search	Control of exposure to cobalt during grinding of hard metal blades, Linnainmaa, appl. occup. environ. hyg. vol.1, no.8, p692, 1995 [16]	workplace C, content of water soluble cobalt in overall exposure is high	semi-automatic machines splash guard without exhaust vs. new splash guards, full enclosure, ducts and fan not changed AND for manual machine splash guard and LEV vs. partial enclosure, ducts and fan not changed	P
E61 (industrial)												
Metal / metallurgical industry	Source segregation	Complete segregation with air supply ventilation / filtered recirculated air	Machining	Metal working fluids (MWF)	Cross-sectional (a-priori design)	0.65	0.29	ECEL	Sheehan et al., metalworking fluid mist - strategies to reduce exposure: a comparison of new and old transmission case transfer lines, J. Occup. Environ. Hyg, vol 4, pp 288-300, 2007 [17]	Fume, but scenario more or less fitting, fume = small particles, i.e. probably similar to solvents	Transfer line installed in the mid-1980s the machines are partial enclosed with local exhaust ventilation installed. vs. Transfer line installed in 1996, the machines are completely enclosed with local exhaust ventialtion installed, personal sampling	P

Metal / metallurgical industry	Source segregation	Complete segregation with air supply ventilation / filtered recirculated air	Machining	Metal working fluids (MWF)	Cross-sectional (a-priori design)	0.13		further evaluation of literature from ECEL	Sheehan et al., metalworking fluid mist - strategies to reduce exposure: a comparison of new and old transmission case transfer lines, J. Occup. Environ. Hyg, vol 4, pp 288-300, 2007 [17]	Fume, but scenario more or less fitting, fume = small particles, i.e. probably similar to solvents	enclosure vs. improved enclosure, update of equipment	P
Metal / metallurgical industry	Containment/ Enclosure	full enclosure, no information about ventilation differences	turning, deburring, millling, drilling, grinding	mwf aerosol	Cross-sectional (a-posteriori design)	0.37		literature search	Lillienberg et al., Exposure to metalworking fluid aerosols and determinants of exposure, ann. occup. hyg. vol. 52, no. 7, pp 597-605, 2008 [18]	derivation of linear mixed effects model, no ventilation differences indicated	completely enclosed machine vs partially enclosed machine	P
Metal / metallurgical industry	Containment/ enclosure	Enclosure+ventilation	Machining	Tracer gas	Intervention	0.02		literature search	Evaluation of leakage from a metal machining center using tracer gas methods: a case study, Heitbrink et al., american industrial hygiene association journal, vol 60, pp 785-788, 1999 [19]	measurement of escaped tracer gas	no control vs. enclosure + ventilation;	s
E61 (professional+industrial)												
Metal / metallurgical industry	Containment/ Enclosure - no extraction; Local ventilation systems - Enclosing hoods	full containment, enclosing hoods	Machining	Metal working fluids (MWF) (gas)	Intervention	0.44	0.18	further evaluation of literature from ECEL	Hands D, Sheehan MJ, Wong B, et al. Comparison of metalworking fluid mist exposures from machining with different levels of machine enclosure. Am Ind Hyg Assoc J. 1996;57:1173–8. [15]	Fume, but scenario more or less fitting, fume = small particles, i.e. probably similar to solvents	no vs. full enclosure	P

Metal / metallurgical industry	Containment/ enclosure	full enclosure, no information about ventilation differences	Milling, drilling,	mwf vapour	Cross-sectional (a-posteriori design)	0.07		literature search	Wahlmüller et al, Reduction and avoidance of lubricant mist demands an integrated assessment approach, J. Environ. Monit. 1999, vol 1, pp 389-396 [20]	average over two times after service, before demisting system, inconsistent results?	full vs. partial enclosure	s
Metal / metallurgical industry	Containment/ enclosure	full enclosure, no information about ventilation differences	Grinding	mwf aerosol	Cross-sectional (a-posteriori design)	0.26		literature search	Wahlmüller et al, Reduction and avoidance of lubricant mist demands an integrated assessment approach, J. Environ. Monit. 1999, vol 1, pp 389-399 [20]	4 and 9 hours after service, no ventilation differences indicated	partial vs. full enclosure	s
Metal / metallurgical industry	Containment/ enclosure	full enclosure, no information about ventilation differences	Grinding	mwf vapour	Cross-sectional (a-posteriori design)	0.16		literature search	Wahlmüller et al, Reduction and avoidance of lubricant mist demands an integrated assessment approach, J. Environ. Monit. 1999, vol 1, pp 389-399 [20]	5 and 9 hours after service, no ventilation differences indicated	partial vs. full enclosure	s
Metal / metallurgical industry	Containment/ enclosure	full enclosure, no information about ventilation differences	Grinding	mwf aerosol and vapour	Cross-sectional (a-posteriori design)	0.21		literature search	Wahlmüller et al, Reduction and avoidance of lubricant mist demands an integrated assessment approach, J. Environ. Monit. 1999, vol 1, pp 389-399 [20]	6 and 9 hours after service, no ventilation differences indicated	partial vs. full enclosure	s
Metal / metallurgical industry	Containment / Ventilation	full enclosure + ventilation	Grinding	total dust	Intervention	0.22		literature search	Control of exposure to cobalt during grinding of hard metal blades, Linnainmaa, appl. occup. environ. hyg. vol.1, no.8, p692, 1995 [16]	workplace A, dust measured but workplace also includes mwf, therefore maybe useful anyway	weak local exhausts vs. new walls around canopy hoods, new ducts and fans	s

Metal / metallurgical industry	Containment / Ventilation	full enclosure + ventilation	Grinding	total dust	Intervention	0.33		literature search	Control of exposure to cobalt during grinding of hard metal blades, Linnainmaa, appl. occup. environ. hyg. vol.1, no.8, p692, 1995 [16]	workplace B, dust measured but workplace also includes mwf, therefore maybe useful anyway	splash guard without exhaust vs. new ducts and fans, improved enclosure	s
Metal / metallurgical industry	Containment / Ventilation	full enclosure + ventilation	Grinding	cobalt exposure	Intervention	0.08		literature search	Control of exposure to cobalt during grinding of hard metal blades, Linnainmaa, appl. occup. environ. hyg. vol.1, no.8, p692, 1995 [16]	workplace A, content of water soluble cobalt in overall exposure is high	weak local exhausts vs. new walls around canopy hoods, new ducts and fans	s
Metal / metallurgical industry	Containment / Ventilation	full enclosure + ventilation	Grinding	cobalt exposure	Intervention	0.03		literature search	Control of exposure to cobalt during grinding of hard metal blades, Linnainmaa, appl. occup. environ. hyg. vol.1, no.8, p692, 1995 [16]	workplace B, content of water soluble cobalt in overall exposure is high	splash guard without exhaust vs. new ducts and fans, improved enclosure	P
Metal / metallurgical industry	Containment / Ventilation	full enclosure + ventilation	Grinding	cobalt (in urine)	Intervention	0.14		literature search	Control of exposure to cobalt during grinding of hard metal blades, Linnainmaa, appl. occup. environ. hyg. vol.1, no.8, p692, 1995 [16]	workplace A, content of water soluble cobalt in overall exposure is high	weak local exhausts vs. new walls around canopy hoods, new ducts and fans	P
Metal / metallurgical industry	Containment / Ventilation	full enclosure + ventilation	Grinding	cobalt (in urine)	Intervention	0.04		literature search	Control of exposure to cobalt during grinding of hard metal blades, Linnainmaa, appl. occup. environ. hyg. vol.1, no.8, p692, 1995 [16]	workplace B, content of water soluble cobalt in overall exposure is high	splash guard without exhaust vs. new ducts and fans, improved enclosure	P
E60 (type of setting unknown)												

Automotive	Personal enclosure / separation	Partial personal enclosure without air supply ventilation / filtered recirculated air	Grinding	Metal working fluids (MWF)	Cross-sectional (a-posteriori design)	0.9	0.86	ECEL	Factors Affecting Worker Exposures to Metal-Working Fluids During Automotive Component Manufacturing, Applied Occupational and Environmental Hygiene Volume 9, Issue 9, 1994, Susan R. Woskie, Thomas J. Smith, S. Katharine Hammond & Marilyn H. Hallock, pages 612-621 [21]	particles < 3.5 microgram, no ventilation	Machininng with partial enclosure vs. complete enclosure,	P
Automotive	Personal enclosure / separation	Complete personal enclosure without air supply ventilation / filtered recirculated air	Grinding	Metal working fluids (MWF)	Cross-sectional (a-posteriori design)	0.74		ECEL	Factors Affecting Worker Exposures to Metal-Working Fluids During Automotive Component Manufacturing, Applied Occupational and Environmental Hygiene Volume 9, Issue 9, 1994, Susan R. Woskie, Thomas J. Smith, S. Katharine Hammond & Marilyn H. Hallock, pages 612-621 [21]	particles > 9.8micrometer, no ventilation	without vs. complete enclosure,	P I
Automotive	Personal enclosure / separation	Complete personal enclosure without air supply ventilation / filtered recirculated air	Grinding	Metal working fluids (MWF)	Cross-sectional (a-posteriori design)	0.84		ECEL	Factors Affecting Worker Exposures to Metal-Working Fluids During Automotive Component Manufacturing, Applied Occupational and Environmental Hygiene Volume 9, Issue 9, 1994, Susan R. Woskie, Thomas J. Smith, S. Katharine Hammond & Marilyn H. Hallock, pages 612-621 [21]	particles > 9.8micrometer, no ventilation	partial vs. complete enclosure,	P I

Automotive	Personal enclosure / separation	Partial personal enclosure without air supply ventilation / filtered recirculated air	Machining	Metal working fluids (MWF)	Cross-sectional (a-posteriori design)	0.91		ECEL	Factors Affecting Worker Exposures to Metal-Working Fluids During Automotive Component Manufacturing, Applied Occupational and Environmental Hygiene Volume 9, Issue 9, 1994, Susan R. Woskie, Thomas J. Smith, S. Katharine Hammond & Marilyn H. Hallock, pages 612-621 [21]	particles > 9.8micrometer, no ventilation	without vs. partial enclosure,	P
Automotive	Personal enclosure / separation	Complete personal enclosure without air supply ventilation / filtered recirculated air	Machining	Metal working fluids (MWF)	Cross-sectional (a-posteriori design)	0.74		ECEL	Factors Affecting Worker Exposures to Metal-Working Fluids During Automotive Component Manufacturing, Applied Occupational and Environmental Hygiene Volume 9, Issue 9, 1994, Susan R. Woskie, Thomas J. Smith, S. Katharine Hammond & Marilyn H. Hallock, pages 612-621 [21]	particles > 9.8micrometer, no ventilation	partial vs. complete enclosure,	P
Automotive	Personal enclosure / separation	Complete personal enclosure without air supply ventilation / filtered recirculated air	Machining	Metal working fluids (MWF)	Cross-sectional (a-posteriori design)	0.81		ECEL	Factors Affecting Worker Exposures to Metal-Working Fluids During Automotive Component Manufacturing, Applied Occupational and Environmental Hygiene Volume 9, Issue 9, 1994, Susan R. Woskie, Thomas J. Smith, S. Katharine Hammond & Marilyn H. Hallock, pages 612-621 [21]	particles > 9.8micrometer, no ventilation	partial vs. complete enclosure,	P

Automotive	Personal enclosure / separation	Complete personal enclosure without air supply ventilation / filtered recirculated air	Grinding	Metal working fluids (MWF)	Cross-sectional (a-posteriori design)	0.95		ECEL	Factors Affecting Worker Exposures to Metal-Working Fluids During Automotive Component Manufacturing, Applied Occupational and Environmental Hygiene Volume 9, Issue 9, 1994, Susan R. Woskie, Thomas J. Smith, S. Katharine Hammond & Marilyn H. Hallock, pages 612-621 [21]	particles < 3.5micrometer, , no ventilation	without vs. complete enclosure	P
Automotive	Personal enclosure / separation	Complete personal enclosure without air supply ventilation / filtered recirculated air	Grinding	Metal working fluids (MWF)	Cross-sectional (a-posteriori design)	0.88		ECEL	Factors Affecting Worker Exposures to Metal-Working Fluids During Automotive Component Manufacturing, Applied Occupational and Environmental Hygiene Volume 9, Issue 9, 1994, Susan R. Woskie, Thomas J. Smith, S. Katharine Hammond & Marilyn H. Hallock, pages 612-621 [21]	particles < 3.5micrometer, no ventilation	partial vs. complete enclosure,	P
Automotive	Personal enclosure / separation	Complete personal enclosure without air supply ventilation / filtered recirculated air	Machining	Metal working fluids (MWF)	Cross-sectional (a-posteriori design)	0.95		ECEL	Factors Affecting Worker Exposures to Metal-Working Fluids During Automotive Component Manufacturing, Applied Occupational and Environmental Hygiene Volume 9, Issue 9, 1994, Susan R. Woskie, Thomas J. Smith, S. Katharine Hammond & Marilyn H. Hallock, pages 612-621 [21]	particles < 3.5micrometer, no ventilation	without vs. complete enclosure	P

Automotive	Personal enclosure / separation	Complete personal enclosure without air supply ventilation / filtered recirculated air	Machining	Metal working fluids (MWF)	Cross-sectional (a-posteriori design)	0.9		ECEL	Factors Affecting Worker Exposures to Metal-Working Fluids During Automotive Component Manufacturing, Applied Occupational and Environmental Hygiene Volume 9, Issue 9, 1994, Susan R. Woskie, Thomas J. Smith, S. Katharine Hammond & Marilyn H. Hallock, pages 612-621 [21]	particles > 9.8micrometer, no ventilation	without vs. partial enclosure,	P
E60 assumed (type of setting unknown)											
Agriculture	Personal enclosure / separation	Not specified, personal enclosure / separation	Spraying	Captan (gas)	Cross-sectional (a-priori design)	0.28	0.28	ECEL	de Vreede et al., Effectiveness of control measures during the application of captan to fruit orchards, TNO nutrition and food research, V3638-revised, 26. sept. 2001 [22]	publication not publicly available, gas instead of solvent (-vapour exposure), no ventilation indicated	Workers at a farm applying pesticides with tractor without cab vs. with cab	P
E61 (professional)											
Agriculture	Containment / Ventilation	ventilated tractor cab	spraying of pesticides	aerosol particles 0.3-0.4 micrometer range	Intervention	0.11	0.06	literature search	Environmental Agricultural Tractor Cab Filter Efficiency and Field Evaluation, Heitbrink et al., AIHA Journal, vol64, pp394-400, 2003 [23]	Aerosol inside vs. outside tractor cab	outside vs. inside aerosol concentrations, tractor in use for 3-4 years	s
Agriculture	Containment / Ventilation	ventilated tractor cab	spraying of pesticides	aerosol particles 0.3-0.4 micrometer range	Intervention	0.00		literature search	Environmental Agricultural Tractor Cab Filter Efficiency and Field Evaluation, Heitbrink et al., AIHA Journal, vol64, pp394-400, 2003 [23]	Aerosol inside vs. outside tractor cab	outside vs. inside aerosol concentrations, tractor cab fixed: leakages detected and closed, filter gasket material replaced	s

Agriculture	Containment / Ventilation	ventilated cab	not defined	fluorescine aerosol	Experimental study	0.20		literature search	Methods for measuring performance of vehicle cab air cleaning systems against aerosols and vapours, Bemer et al., Ann. Occup. Hyg. vol53, No 4, pp441-447, 2009 [24]		inside vs. outside ventilated vehicle cab	stationary
Agriculture	Containment / Ventilation	ventilated cab	not defined	dust particles > 3 micrometers	Experimental study	< 0.01		literature search	Evaluation of a tractor cab using real-time aerosol counting instrumentation, Hall et al., Applied occupational and Environmental hygiene, vol17, No1, pp47-54, 2002 [25]	John Deere Tractor cab	inside vs. outside ventilated vehicle cab. particles size distribution for pesticide measured for comparison: depending on nozzle design between 3 and 23% smaller than 3 micrometer.	s
Agriculture	Containment / Ventilation	ventilated cab	not defined	dust particles > 3 micrometers	Experimental study	< 0.01		literature search	Evaluation of a tractor cab using real-time aerosol counting instrumentation, Hall et al., Applied occupational and Environmental hygiene, vol17, No1, pp47-54, 2002 [25]	Nelson spray cab designed to fit on Massy Ferguson tractor	inside vs. outside ventilated vehicle cab. particles size distribution for pesticide measured for comparison: depending on nozzle design between 3 and 23% smaller than 3 micrometer.	s

Agriculture	Containment / Ventilation	ventilated cab	not defined	dust particles < 3 micrometers	Experimental study	0.02		literature search	Evaluation of a tractor cab using real-time aerosol counting instrumentation, Hall et al., Applied occupational and Environmental hygiene, vol17, No1, pp47-54, 2002 [25]	John Deere Tractor cab	inside vs. outside ventilated vehicle cab. particles size distribution for pesticide measured for comparison: depending on nozzle design between 3 and 23% smaller than 3 micrometer.	s
Agriculture	Containment / Ventilation	ventilated cab	not defined	dust particles < 3 micrometers	Experimental study	0.06		literature search	Evaluation of a tractor cab using real-time aerosol counting instrumentation, Hall et al., Applied occupational and Environmental hygiene, vol17, No1, pp47-54, 2002 [25]	Nelson spray cab designed to fit on Massy Ferguson tractor	inside vs. outside ventilated vehicle cab. particles size distribution for pesticide measured for comparison: depending on nozzle design between 3 and 23% smaller than 3 micrometer.	s
E61 (type of setting unknown)												
Manufacturing of chemicals	Local ventilation systems - Enclosing hoods	full enclosure+ventilation	Mixing in tanks / manufacture of paraquat	4,4'-Bipyridyl aerosol	Intervention	0.12	0.15	literature search	Occupational expousre to 4,4'-bipyridyl vapour and aerosol during paraquat manufacturing, Kuo et al., Am. ind. hyg. assoc. j. vol 54, p440, 1993 [26]		no enclosure vs. full enclosure of machine (hood + suction tube)	s

Manufacturing of chemicals	Local ventilation systems - Enclosing hoods	Enclosure+ventilation	Mixing in tanks / manufacture of paraquat	4,4'-Bipyridyl vapour	Intervention	0.18		literature search	Occupational expousre to 4,4'-bipyricyl vapour and aerosol during paraquat manufacturing, Kuo et al., Am. ind. hyg. assoc. j. vol 54, p440, 1993 [26]		no enclosure vs. full enclosure of machine (hood + suction tube)	a
E60 (type of setting unknown)												
Paint manufacture	Local ventilation systems + General dilution ventilation	not further defined	Mixing, milling, shearing (canning)	Benzene	Intervention	0.141	0.37	literature search	Jafari et al., The role of exhaust ventilation systems in reducing occupational exposure to organic solvents in a paint manufacturing factory, Indian J. Occup. Environ. Med. Vol 12, No 2,. pp 82-87, 2008 [27]	no containment strategy, only ventilation systems; no mechanical ventilation vs. LEV+general ventilation	with vs. without LEV systems	P
Paint manufacture	Local ventilation systems + General dilution ventilation	not further defined	Mixing, milling, shearing (canning)	Toluene	Intervention	0.42		literature search	Jafari et al., The role of exhaust ventilation systems in reducing occupational exposure to organic solvents in a paint manufacturing factory, Indian J. Occup. Environ. Med. Vol 12, No 2,. pp 82-87, 2008 [27]	no containment strategy, only ventilation systems; no mechanical ventilation vs. LEV+general ventilation	with vs. without LEV systems	P
Paint manufacture	Local ventilation systems + General dilution ventilation	not further defined	Mixing, milling, shearing (canning)	P and M-Xylene	Intervention	0.39		literature search	Jafari et al., The role of exhaust ventilation systems in reducing occupational exposure to organic solvents in a paint manufacturing factory, Indian J. Occup. Environ. Med. Vol 12, No 2,. pp 82-87, 2008 [27]	no containment strategy, only ventilation systems; no mechanical ventilation vs. LEV+general ventilation	with vs. without LEV systems	P

Paint manufac ture	Local ventilation systems + General dilution ventilation	not further defined	Mixing, milling, shearing (canning)	O-Xylene	Intervent ion	0.54		literatu re search	Jafari et al., The role of exhaust ventilation systems in reducing occupational exposure to organic solvents in a paint manufacturing factory, Indian J. Occup. Environ. Med. Vol 12, No 2,. pp 82-87, 2008 [27]	no containment strategy, only ventilation systems; no mechanical ventilation vs. LEV+general ventilation	with vs. without LEV systems	P
E60 assumed (professional)												
Paint / Coatings	Enclosure (process implemented)	exchange of spray gun	spray painting (cars)	overspra y particles	Cross-sectional (a-posterior i design)	0.50	0.50	literatu re search	Control of paint overspray in autobody repair shops, Heitbrink et al., Am. ind. hyg. assoc. J. vol. 56, pp 1023-1032, 1995 [28]	small dataset, single tasks/ workplaces have been compared, other parts of equipment also seem to have significant influence, average exposure value, not scaled to period spent painting, derivation of efficiency not entirely reproducible	exchange of spray gun (old: conventional, new: high volume low pressure spray painting gun)	P
E60 (professional)												
Fuels	Enclosure (process implemented)	vapour recovery system	refuellin g, fuel stations attendan ts	aromatic hydrocar bons	Intervent ion	0.22	0.31	literatu re search	Evolution of Occupational Exposure to Environmental Levels of Aromatic Hydrocarbons in Service Stations, J. F. Periago and C. Prado, Ann. occup. Hyg., Vol. 49, No. 3, pp. 233–240, 2005 [29]	containment?	personal sampling of service station attendants before and after installation of vapour recovery systems at refueling stations,	P

Fuels	Enclosure (process implemented)	vapour recovery system	refuelling, fuel stations attendants	benzene	Intervention	0.19		literature search	Evolution of Occupational Exposure to Environmental Levels of Aromatic Hydrocarbons in Service Stations, J. F. Periago and C. Prado, Ann. occup. Hyg., Vol. 49, No. 3, pp. 233–240, 2005 [29]	containment?, GM used	personal sampling of service station attendants before and after installation of vapour recovery systems at refueling stations,	P
Fuels	Enclosure (process implemented)	vapour recovery system	refuelling, fuel stations attendants	toluene	Intervention	0.55		literature search	Evolution of Occupational Exposure to Environmental Levels of Aromatic Hydrocarbons in Service Stations, J. F. Periago and C. Prado, Ann. occup. Hyg., Vol. 49, No. 3, pp. 233–240, 2005 [29]	containment?, GM used	personal sampling of service station attendants before and after installation of vapour recovery systems at refueling stations,	P
Fuels	Enclosure (process implemented)	vapour recovery system	refuelling, fuel stations attendants	xylenes	Intervention	0.56		literature search	Evolution of Occupational Exposure to Environmental Levels of Aromatic Hydrocarbons in Service Stations, J. F. Periago and C. Prado, Ann. occup. Hyg., Vol. 49, No. 3, pp. 233–240, 2005 [29]	containment?, GM used	personal sampling of service station attendants before and after installation of vapour recovery systems at refueling stations,	P
Fuels	Enclosure (process implemented)	vapour recovery system	loading, tanker drivers	aliphatic hydrocarbons	Intervention	0.13		literature search	Comparison of tanker drivers' occupational exposures before and after the installation of a vapour recovery system, Saarinen et al., J. Environ. Monit., 2000, 2, 662±665 [30]	containment?, GM used	personal sampling of tanker drivers before and after installation of vapour recovery systems at refueling stations,	P

Fuels	Enclosure (process implemented)	vapour recovery system	loading, tanker drivers	MTBE	Intervention	0.17		literature search	Comparison of tanker drivers' occupational exposures before and after the installation of a vapour recovery system, Saarinen et al., J. Environ. Monit., 2000, 2, 662±665 [30]	containment?, GM used	personal sampling of tanker drivers before and after installation of vapour recovery systems at refueling stations,	P
Fuels	Enclosure (process implemented)	vapour recovery system	loading, tanker drivers	Benzene	Intervention	0.32		literature search	Comparison of tanker drivers' occupational exposures before and after the installation of a vapour recovery system, Saarinen et al., J. Environ. Monit., 2000, 2, 662±665 [30]	containment?, GM used	personal sampling of tanker drivers before and after installation of vapour recovery systems at refueling stations,	P
E60 (professional and industrial)												
Rubber industry	Local ventilation systems	autoclave with LEV vs. autoclave without LEV	Curing	respirable particulate	Cross-sectional (a-posteriori design)	0.24	0.57	literature search	Kromhout et al., empirical modelling of c hemical exposure in the rubber-manufacturing industry, ann. occup. hyg. vol. 38, No. 1, pp 3-22, 1994 [31]	RMM description not exactly fitting, no solvent exposure, but industry and task can also be solvent related	autoclave with LEV vs. autoclave without LEV. 85.6% efficiency for gloves (lubricating during engineering services) indicated)	P

Rubber industry	Local exhaust ventilation	no enclosure specified	diverse (compounding, moulding, curing, finishing etc.)	Inhalable particulate	Intervention	0.89		literature search	Trends in exposure to inhalable particulate and dermal contamination in the rubber manufacturing industry: effectiveness of control measures implemented over a nine-year period; Vermeulen et al., Am. occup. Hyg. Vol. 44, NO5, pp 343-354, 2000 [32]	also other influences described but nothing directly related to ESIG RMMs. Anova modelling	with vs. without LEV	P
E60 (professional and industrial)												
Rubber industry	Local ventilation systems	with brush and LEV vs. with brush without LEV	Cementing	solvents	Cross-sectional (a-posteriori design)	0.32	0.32	literature search	Kromhout et al., empirical modelling of chemical expousre in the rubber-manufacturing industry, ann. occup. hyg. vol. 38, No. 1, pp 3-22, 1994 [31]	RMM description not exactly fitting, total exposure (dermal + inhalation), but industry and task can also be solvent related	with brush and LEV vs. with brush without LEV	P
E60 (professional)												
Health care / Medicine	partial containment/ ventilation	installation of ventilated tables (tables can be closed)	Dissecting	formaldehyde	Intervention	0.06	0.10	literature search	Controlling formaldehyde exposures in an academic gross anatomy laboratory, Klein et al., Journal of occupational and environmental hygiene, vol11, pp127-132, 2014 [33]	no solvent, specific equipment	before and after installation of ventilated tables	P
Health care / Medicine	Containment / Ventilation	level of containment not specified, with and without ventilated enclosure	sterilising	ethylene oxide	Intervention	0.21		literature search	Before and after: an evaluation of engineering controls for ethylene oxide sterilization in hospitals, Kercher and Mortimer, Appl. ind. hyg. vol.2, No 1, p7, 1987 [35]	not solvent specific, full shift, operator exposure	with and without enclosure + ventilation	P

Health care / Medicine	Local ventilation systems - enclosing hoods	Containment hoods and ventilation changes	administ ration of pentami dine	pentami dine	Intervent ion	0.02		literatu re search	McDiarmid et al., Efficacy of engineering controls in reducing occupational exposure to aerosolized pentamidine, Chest 1992, vol. 102, pp 1764-66 [34]	no solvent typical handling, aerosol exposure, no containment vs. Containment hoods and ventilation changes	with vs. without containment hoods, also ventilation changes implemented	P
E60 (type of setting undefined)												
not defined	Partial containment / Ventilation	wake-controlled exterior hood	not defined	tracer gas	Experim ental study	0.72	0.11	literatu re search	Development and characterisation of a wake controlled exterior hood, Huang et al., journal of occupational and environmental hygiene, 2004, vol1, pp769-778 [38]	factor eta (=concentration in hood exhaust pipe / concentration at exit of worktable top) as efficiency measured, without blockage plate	concentration in hood exhaust pipe / concentration at exit of worktable top	s
not defined	Partial containment / Ventilation	wake-controlled exterior hood	not defined	tracer gas	Experim ental study	0.48		literatu re search	Development and characterisation of a wake controlled exterior hood, Huang et al., journal of occupational and environmental hygiene, 2004, vol1, pp769-778 [38]	factor eta (=concentration in hood exhaust pipe / concentration at exit of worktable top) as efficiency measured, with blockage plate	concentration in hood exhaust pipe / concentration at exit of worktable top	s
not defined	Local ventilation systems	Local ventilation systems, extracted partial enclosure	drum filling	tracer gas	Experim ental study	~0.0 1		literatu re search	Batt et al., Analysis of factors affecting containment with extracted partial enclosures using computational fluid dynamics, Ann occup. hyg, 2013, doi: 10.1093/annhyg/met061 [37]	semi quantitative according to graphical figure	tracer concentrations inside and outside enclosure	s

not defined	Local ventilation systems / enclosing hoods	partial enclosure+ ventilation	not defined	tracer gas	Experimental study	0.2400		literature search	Sulfur hexafluoride tracer gas evaluations on hood exhaust reductions, Mosovsky J.A. Am ind. hyg. assoc. J. vol56, No 1, pp44-49, 1995 [36]	inside vs. outside concentration of tracer gas in ppm, partial enclosure with ventilation vs. no enclosure, different hood types and ejector positions, different exhaust volumes, cfm and operating mode, no actual process or task avaluated	inside vs. outside hood concentration of tracer gas in ppm, partial enclosure with ventilation vs. no enclosure, electroless tool, below deck plenum exhaust slots closed ejector in sunken bath, 800 exhaust volume, initial test	s
not defined	Local ventilation systems / enclosing hoods	partial enclosure+ ventilation	not defined	tracer gas	Experimental study	0.0012		literature search	Sulfur hexafluoride tracer gas evaluations on hood exhaust reductions, Mosovsky J.A. Am ind. hyg. assoc. J. vol56, No 1, pp44-49, 1996 [36]	inside vs. outside concentration of tracer gas in ppm, partial enclosure with ventilation vs. no enclosure, different hood types and ejector positions, different exhaust volumes, cfm and operating mode, no actual process or task avaluated	electroless tool, ejector in sunken bath, 1400 exhaust volume full exhaust	s

not defined	Local ventilation systems / enclosing hoods	partial enclosure+ ventilation	not defined	tracer gas	Experimental study	0.0024		literature search	Sulfur hexafluoride tracer gas evaluations on hood exhaust reductions, Mosovsky J.A. Am ind. hyg. assoc. J. vol56, No 1, pp44-49, 1997 [36]	inside vs. outside concentration of tracer gas in ppm, partial enclosure with ventilation vs. no enclosure, different hood types and ejector positions, different exhaust volumes, cfm and operating mode, no actual process or task avaluated	inside vs. outside hood concentration of tracer gas in ppm, partial enclosure with ventilation vs. no enclosure, electroless tool, ejector in sunken bath, 1100 exhaust volume, 20% full exhaust	s
not defined	Local ventilation systems / enclosing hoods	partial enclosure+ ventilation	not defined	tracer gas	Experimental study	0.0007		literature search	Sulfur hexafluoride tracer gas evaluations on hood exhaust reductions, Mosovsky J.A. Am ind. hyg. assoc. J. vol56, No 1, pp44-49, 1998 [36]	inside vs. outside concentration of tracer gas in ppm, partial enclosure with ventilation vs. no enclosure, different hood types and ejector positions, different exhaust volumes, cfm and operating mode, no actual process or task avaluated	inside vs. outside hood concentration of tracer gas in ppm, partial enclosure with ventilation vs. no enclosure, electroless tool, ejector in sunken bath with cover on, 1100 exhaust volume, 20% full exhaust	s
not defined	Local ventilation systems / enclosing hoods	partial enclosure+ ventilation	not defined	tracer gas	Experimental study	0.0002		literature search	Sulfur hexafluoride tracer gas evaluations on hood exhaust reductions, Mosovsky J.A. Am ind. hyg. assoc. J. vol56, No 1, pp44-49, 1999 [36]	inside vs. outside concentration of tracer gas in ppm, partial enclosure with ventilation vs. no enclosure, different hood types and ejector positions, different exhaust volumes, cfm and operating mode, no actual process or task avaluated	inside vs. outside hood concentration of tracer gas in ppm, partial enclosure with ventilation vs. no enclosure, precious metals tool, ejector in sunken bath, 1500 exhaust volume, full exhaust	s

not defined	Local ventilation systems / enclosing hoods	partial enclosure+ ventilation	not defined	tracer gas	Experimental study	0.0004		literature search	Sulfur hexafluoride tracer gas evaluations on hood exhaust reductions, Mosovsky J.A. Am ind. hyg. assoc. J. vol56, No 1, pp44-49, 2000 [36]	inside vs. outside concentration of tracer gas in ppm, partial enclosure with ventilation vs. no enclosure, different hood types and ejector positions, different exhaust volumes, cfm and operating mode, no actual process or task avaluated	inside vs. outside hood concentration of tracer gas in ppm, partial enclosure with ventilation vs. no enclosure, precious metals tool, ejector in sunken bath, 1200 exhaust volume, 20% exhaust	s
not defined	Local ventilation systems / enclosing hoods	partial enclosure+ ventilation	not defined	tracer gas	Experimental study	0.3700		literature search	Sulfur hexafluoride tracer gas evaluations on hood exhaust reductions, Mosovsky J.A. Am ind. hyg. assoc. J. vol56, No 1, pp44-49, 2001 [36]	inside vs. outside concentration of tracer gas in ppm, partial enclosure with ventilation vs. no enclosure, different hood types and ejector positions, different exhaust volumes, cfm and operating mode, no actual process or task avaluated	inside vs. outside hood concentration of tracer gas in ppm, partial enclosure with ventilation vs. no enclosure, precious metals tool, ejector on top of hood deck, six inches from rear slot, 1500 exhaust volume, full exhaust	s

not defined	Local ventilation systems / enclosing hoods	partial enclosure+ ventilation	not defined	tracer gas	Experimental study	0.0004		literature search	Sulfur hexafluoride tracer gas evaluations on hood exhaust reductions, Mosovsky J.A. Am ind. hyg. assoc. J. vol56, No 1, pp44-49, 2002 [36]	inside vs. outside concentration of tracer gas in ppm, partial enclosure with ventilation vs. no enclosure, different hood types and ejector positions, different exhaust volumes, cfm and operating mode, no actual process or task avaluated	inside vs. outside hood concentration of tracer gas in ppm, partial enclosure with ventilation vs. no enclosure, photoresist etch, ejector in sunken bath, 3450 exhaust volume, full exhaust	s
not defined	Local ventilation systems / enclosing hoods	partial enclosure+ ventilation	not defined	tracer gas	Experimental study	0.0006		literature search	Sulfur hexafluoride tracer gas evaluations on hood exhaust reductions, Mosovsky J.A. Am ind. hyg. assoc. J. vol56, No 1, pp44-49, 2003 [36]	inside vs. outside concentration of tracer gas in ppm, partial enclosure with ventilation vs. no enclosure, different hood types and ejector positions, different exhaust volumes, cfm and operating mode, no actual process or task avaluated	inside vs. outside hood concentration of tracer gas in ppm, partial enclosure with ventilation vs. no enclosure, photoresist etch, ejector on top of bath cover, 3450 exhaust volume, full exhaust	s

not defined	Local ventilation systems / enclosing hoods	partial enclosure+ ventilation	not defined	tracer gas	Experimental study	0.0007		literature search	Sulfur hexafluoride tracer gas evaluations on hood exhaust reductions, Mosovsky J.A. Am ind. hyg. assoc. J. vol56, No 1, pp44-49, 2004 [36]	inside vs. outside concentration of tracer gas in ppm, partial enclosure with ventilation vs. no enclosure, different hood types and ejector positions, different exhaust volumes, cfm and operating mode, no actual process or task avaluated	inside vs. outside hood concentration of tracer gas in ppm, partial enclosure with ventilation vs. no enclosure, photoresist etch, ejector on top of bhood deck, six inches from rear slots, 3450 exhaust volume, full exhaust	s
not defined	Local ventilation systems / enclosing hoods	partial enclosure+ ventilation	not defined	tracer gas	Experimental study	0.0005		literature search	Sulfur hexafluoride tracer gas evaluations on hood exhaust reductions, Mosovsky J.A. Am ind. hyg. assoc. J. vol56, No 1, pp44-49, 2005 [36]	different hood types and ejector positions, different exhaust volumes, cfm and operating mode, no actual process or task avaluated	inside vs. outside hood concentration of tracer gas in ppm, partial enclosure with ventilation vs. no enclosure, photoresist etch, ejector in sunken bath , 2760 exhaust volume, 20% exhaust reduction	s

not defined	Local ventilation systems / enclosing hoods	partial enclosure+ ventilation	not defined	tracer gas	Experimental study	0.0003		literature search	Sulfur hexafluoride tracer gas evaluations on hood exhaust reductions, Mosovsky J.A. Am ind. hyg. assoc. J. vol56, No 1, pp44-49, 2006 [36]	different hood types and ejector positions, different exhaust volumes, cfm and operating mode, no actual process or task avaluated	inside vs. outside hood concentration of tracer gas in ppm, partial enclosure with ventilation vs. no enclosure, photoresist etch, ejector on top of bath cover, 2760 exhaust volume, 20% exhaust reduction	s
not defined	Local ventilation systems / enclosing hoods	partial enclosure+ ventilation	not defined	tracer gas	Experimental study	0.0003		literature search	Sulfur hexafluoride tracer gas evaluations on hood exhaust reductions, Mosovsky J.A. Am ind. hyg. assoc. J. vol56, No 1, pp44-49, 2007 [36]	different hood types and ejector positions, different exhaust volumes, cfm and operating mode, no actual process or task avaluated	inside vs. outside hood concentration of tracer gas in ppm; partial enclosure with ventilation vs. no enclosure, photoresist etch, ejector on top of hood deck, six inches from rear slots, 2760 exhaust volume, 20% exhaust reduction	s

APPENDIX C: EXPERIMENTAL STUDIES

EXPERIMENTAL SET-UP

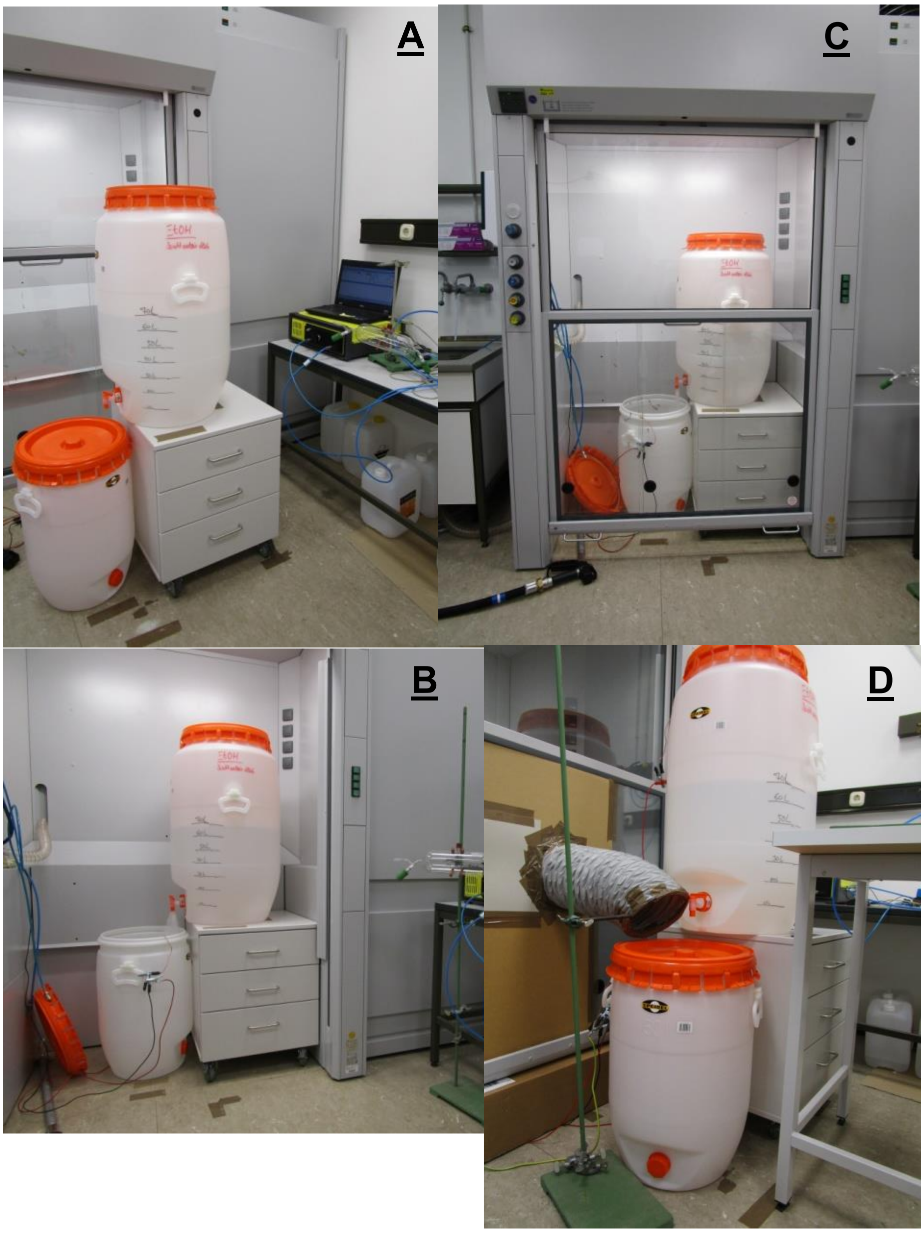

Fig. A 1: **Gravity transfer: Experimental set-up for <u>A:</u> Scenario #1, <u>B:</u> Scenario #2, <u>C:</u> Scenario #3 and <u>D:</u> Scenario #4.**

Fig. A 2: Drum pump transfer: Experimental set-up for A: Scenario #5, B: Scenario #6, C: Scenario # 7 and D: Scenario #7a.

IMPLEMENTATION OF SCENARIOS IN LABORATORY BASED SIMULATIONS

Table 20: Scenario #1: Description of the scenario and its simulation at the test facility.

#	Scenario	Description	Description - Simulation
No local exhaust ventilation in place			
1	Baseline – Gravity transfer from an open container into another open container	• Ethanol (50 L) is transferred from an open reservoir container into a fully open container collection via a tap (splash loading) • Outside fume cupboard • Experiment will be repeated up to five times (min. three times)	• Reservoir and collection container are placed outside the fume hood. (The fume hood sash is fully closed.) • After a stable ethanol background concentration (below 25 ppm) has been reached the lids of the reservoir and collection container are removed. The spigot on the reservoir container is opened. • 50 L ethanol are transferred via gravity transfer. • The spigot on the reservoir container and the lids of the collection and reservoir container are closed. • Analysts leave the room to keep air movement in the room to a minimum while the ethanol concentration in the room distributes/declines. A duration of approx. 30 min was considered to be sufficient. • The ethanol is transferred back into the reservoir container. • The room is vented to remove residual ethanol vapour in the room. • The next scenario #1 simulation is conducted when a stable ethanol background concentration of below 25 ppm is reached.

Table 21: Scenario #2 and #3: Description of the scenarios and their simulations at the test facility.

#	Scenario	Description - Scenario	Description - Simulation
Fume cupboard LEV in place – partial & full			
2	Open gravity transfer with partial enclosure (inside open fume cupboard) into a container. Room ventilation and fume cupboard switched on.	• Ethanol (50 L) is transferred from a closed reservoir container into a fully open collection container via a tap (splash loading) • Inside fume cupboard with the sash fully open (ventilation switched on). • Experiment will be repeated up to five times (min. three times) *Phrase: E60 'Minimise exposure by partial enclosure of the operation or equipment and provide extract ventilation at openings'*	• Reservoir and collection container are placed in the fume hood with the sash being fully opened • After a stable ethanol background concentration (below 5 ppm) is reached the lid of the collection container is removed and the spigot on the reservoir container is opened. The reservoir container lid remains closed during the simulation. • 50L ethanol are transferred via gravity transfer. • The spigot on the reservoir container and the lid of the collection container are closed. • Analysts leave the room to keep air movement in the room to a minimum while the ethanol concentration in the room distributes/declines. • The ethanol is transferred back into the reservoir container. • The room is vented to remove residual ethanol vapour in the room. • The next scenario #2 simulation is conducted when a stable ethanol background concentration of below 5 ppm is reached.
3	Open gravity transfer with full enclosure (inside closed fume cupboard) into a container. Room ventilation and fume cupboard switched on.	• Ethanol (50 L) is transferred from a closed reservoir container into a fully open collection container via a tap (splash loading) • Inside fume cupboard with the sash fully closed (ventilation switched on). • Experiment will be repeated up to five times (min. three times) *Phrase: E61 Minimise exposure by extracted full enclosure for the operation or equipment*	• Reservoir and collection container are placed in the fume hood with the sash being fully closed. • After a stable ethanol background concentration (below 5 ppm) is reached the lid of the collection container is removed and the spigot on the reservoir container is opened. The reservoir container lid remains closed during the simulation.50L EtOH are transferred via gravity transfer. • The spigot on the reservoir container and the lid of the collection container are closed. • 50L ethanol are transferred via gravity transfer. • The spigot on the reservoir container and the lid of the collection container are closed. • As no increase in the ethanol background concentration was observed the ethanol was transferred back into the reservoir container shortly (approx. after 5 min) after closing the spigot. • The room is vented to remove residual ethanol vapour in the room. The vapour was released during the back transfer of ethanol into the reservoir container. • The next scenario #3 simulation is conducted when a stable ethanol background concentration of below 5 ppm is reached.

Table 22: Scenario #4: Description of the scenario and its simulation at the test facility.

#	Scenario	Description - Scenario	Description - Simulation
"Elephant trunk" LEV in place			
4	Gravity transfer from an open container into another open container – application of a local exhaust system (LEV, elephant trunk) and no enclosure (outside fume cupboard). Room ventilation switched on.	• Ethanol (50 L) is transferred from an open reservoir container into a fully open collection container via a tap (splash loading) outside the fume hood. • "Elephant trunk" will be place above max. filling level of collection container • Experiment will be repeated up to five times (min. three times) *Phrase: E54 'Provide extract ventilation to points where emissions occur'* *Phrase: E66 'Ensure material transfers are under containment or extract ventilation'*	• Reservoir and collection container are place outside the fume hood. • The sash is fully closed with the "Elephant Trunk" LEV being installed. The air flow at the centre of the "Elephant Trunk" was approx. 1m / sec. The "Elephant Trunk" is positioned above the spigot of the reservoir container (= exposure source) and thereby also above the max. filling level of the collection container. • Ventilation is switched on. • After a stable ethanol background concentration (below 5 ppm) is reached the lids of the reservoir and collection container are removed. The spigot on the reservoir container is opened. • 50L ethanol are transferred via gravity transfer. • The spigot on the reservoir container and the lids of the collection and reservoir container are closed. • Analysts leave the room to keep air movement in the room to a minimum while the ethanol concentration in the room distributes/declines. • The ethanol is transferred back into the reservoir container. • The room is vented to remove residual ethanol vapour in the room. • The next scenario #4 simulation is conducted when a stable ethanol background concentration of below 5 ppm is reached.

Table 23: Scenario #5 and #6: Description of the scenarios and their simulations at the test facility.

#	Scenario	Description	Description - Simulation
5	Drum pump transfer (lids on containers) with no exhaust and no room ventilation– accurate use of drum pump (submerged loading)	• Ethanol (50 L) is transferred from a closed reservoir container into a collection container via an open bung hole using a drum pump (submerged loading) • Outside fume cupboard • Experiment will be repeated up to five times (min. three times) *Phrase: E53 ' Use of drum pump'* *(Phrase: E68, 'Restrict area of openings to equipment')21*	• Reservoir and collection container are placed outside the fume hood. (The fume hood sash is fully closed.) The drum pump is placed in the reservoir container via the bung hole. The pump nozzle (lance) is placed in the collection container via the bung hole. Paper towels are used to seal the remaining openings at the bung holes. • After a stable ethanol background concentration (below 5 ppm) is reached the paper towels are removed and the drum pump transfer is started (50 L ethanol). • After the transfer the drum pump and pump nozzle (lance) remain in the drums. The small openings at the bung holes are closed with paper towels. • Analysts leave the room to keep air movement in the room to a minimum while the ethanol concentration in the room distributes/declines. • The ethanol is transferred back into the reservoir container. • The room is vented to remove residual ethanol vapour in the room. • The next scenario #5 simulation is conducted when a stable ethanol background concentration of below 5 ppm is reached.
6	Drum pump transfer (lids on containers) with partial enclosure (inside open fume cupboard) – accurate use of drum pump (submerged loading). Room ventilation and fume cupboard switched on	• Ethanol (50 L) is transferred from a closed reservoir container into a collection container via an open bung hole using a drum pump (submerged loading) • Inside fume cupboard • Sash fully open and ventilation on. • Experiment will be repeated up to five times (min. three times) *Phrase: E66 'Ensure material transfers are under containment or extract ventilation.' and* *Phrase: E53 ' Use of drum pump'* *(Phrase: E68, 'Restrict area of openings to equipment')[11]*	• Reservoir and collection container are placed inside the fume hood. (The fume hood sash is fully open.) The ventilation is switched on. The drum pump is placed in the reservoir container via the bung hole. The pump nozzle (lance) is placed in the collection container via the bung hole. Paper towels are used to seal the remaining openings at the bung holes. • After a stable ethanol background concentration (below 5 ppm) is reached the paper towels are removed and the drum pump transfer is started (50 L ethanol). • After the transfer the drum pump and pump nozzle (lance) remain in the drums. The small openings at the bung holes are closed with paper towels. • Analysts leave the room to keep air movement in the room to a minimum while the ethanol concentration in the room distributes/declines. • The ethanol is transferred back into the reservoir container. • The room is vented to remove residual ethanol vapour in the room. • The next scenario #6 simulation is conducted when a stable ethanol background concentration of below 5 ppm is reached.

[21] Standard handling for solvents.

Table 24: Scenario #7 and #7a: Description of the scenarios and their simulations at the test facility.

#	Scenario	Description	Description - Simulation
7	Drum pump transfer (lids on containers), room ventilation and a local exhaust ventilation system in place (elephant trunk) – accurate use of drum pump (submerged loading)	• Ethanol (50 L) is transferred from a closed reservoir container into a collection container via an open bung hole using a drum pump (submerged loading) • Outside fume cupboard • Elephant trunk lev switched on • Experiment will be repeated up to five times (min. three times) *Phrase: E54 'Provide extract ventilation to points where emissions occur' or* *Phrase: E66 'Ensure material transfers are under containment or extract ventilation.' and* *Phrase: E53 ' Use of drum pump'* *(Phrase: E68, 'Restrict area of openings to equipment')* [11]	• Reservoir and collection container are placed outside the fume hood. The drum pump is placed in the reservoir container via the bung hole. The pump nozzle (lance) is placed in the collection container via the bung hole. Paper towels are used to seal the remaining openings at the bung holes. • The sash is fully closed with the "Elephant Trunk" LEV being installed. The air flow at the centre of the "Elephant Trunk" was approx. 1m / sec. The "Elephant Trunk" is positioned above the bung hole of the collection container (= exposure source) and thereby also above the max. filling level of the collection container. • Ventilation is switched on. • After a stable ethanol background concentration (below 5 ppm) is reached the paper towels are removed and the drum pump transfer is started (50 L ethanol). • After the transfer the drum pump and pump nozzle (lance) remain in the drums. The small openings at the bung holes are closed with paper towels. • Analysts leave the room to keep air movement in the room to a minimum while the ethanol concentration in the room distributes/declines. • The ethanol is transferred back into the reservoir container. • The room is vented to remove residual ethanol vapour in the room. • The next scenario #7 simulation is conducted when a stable ethanol background concentration of below 5 ppm is reached.
7a	Base Configuration for scenario 7: Drum pump transfer (lids on containers) room ventilation, but no local exhaust system in place – accurate use of drum pump (submerged loading)	• Ethanol (50 L) is transferred from a closed reservoir container into a collection container via an open bung hole using a drum pump (submerged loading) • Outside fume cupboard • Elephant trunk lev switched "off" • Experiment will be repeated up to five times (min. three times) *Baseline for scenario 7 as in both cases the room ventilation and the fume hood were switched on* *Phrase: E53 ' Use of drum pump'* *(Phrase: E68, 'Restrict area of openings to equipment')* [11]	• Same set-up as for #7 with only difference being that the "Elephant Trunk" is moved away from the exposure source and its opening is covered with e.g. card board.

Table 25: Scenario #8 and #9: Description of the scenarios and their simulations at the test facility.

#	Scenario	Description	Description - Simulation
8	Base Configuration for scenario 9: Drained container without flushing with no exhaust and ventilation system in place	• Measure just drained ethanol container. • Outside fume cupboard, no lev • Experiment will be repeated up to five times (min. three times)	• Reservoir and collection container are placed outside the fume hood. (The fume hood sash is fully closed.) • The collection container is rinsed with 1 x 5L EtOH (outside of the room). • After a stable ethanol background concentration (below 5 ppm) is reached the lid of the collection container is removed. • The lid of the collection container is closed again after a fixed time window. • Analysts leave the room to keep air movement in the room to a minimum while the ethanol concentration in the room distributes/declines. • The room is vented to remove residual ethanol fumes in the room. • The next scenario #8 simulation is conducted when a stable ethanol background concentration of below 5 ppm is reached.
9	Flushed container with no exhaust and ventilation system in place	• Flush drained ethanol container with water • Outside fume cupboard, no lev • Experiment will be repeated up to five times (min. three times) *Phrase: E55 'Drain down and flush system prior to equipment break-in or maintenance.'*	• Reservoir and collection container are placed outside the fume hood. (The fume hood sash is fully closed.) • The collection container is rinsed with 1 x 5L EtOH and 2x 10L water (outside of the room). • After a stable ethanol background concentration (below 5 ppm) is reached the lid of the collection container is removed. • The lid of the collection container is closed again after a fixed time window. • Analysts leave the room to keep air movement in the room to a minimum while the ethanol concentration in the room distributes/declines. • The room is vented to remove residual ethanol fumes in the room. • The next scenario #9 simulation is conducted when a stable ethanol background concentration of below 5 ppm is reached.

SCENARIO #1

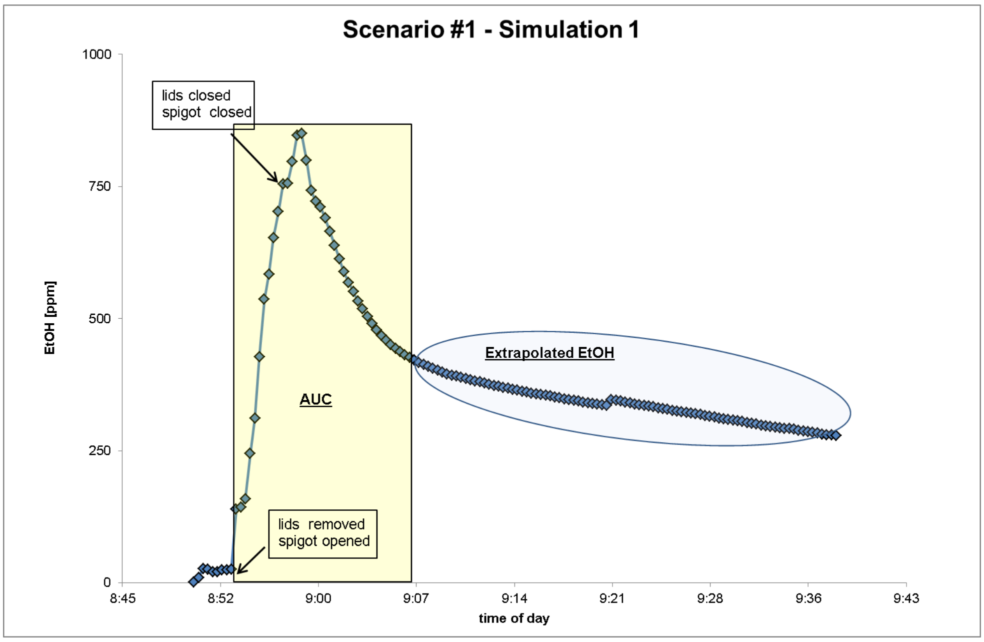

Fig. A 3 **Scenario # 1; Simulation 1 - time of day vs ethanol concentration plot. Data points used for the calculation of the AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) are marked by a yellow rectangle. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval.**

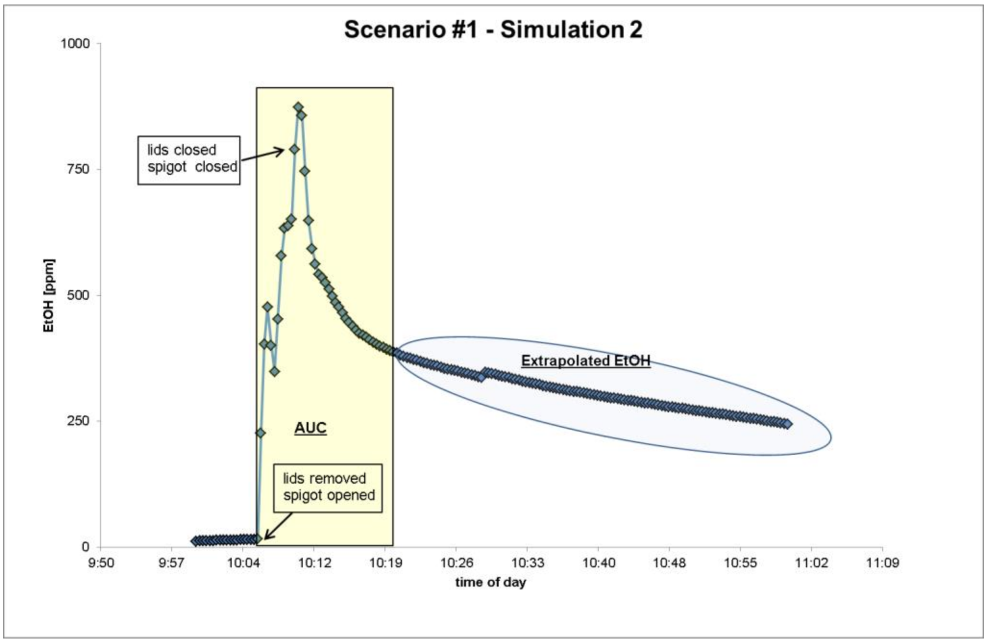

Fig. A 4: **Scenario # 1; Simulation 2 - time of day vs ethanol concentration plot. Data points used for the calculation of the AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) are marked by a yellow rectangle. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval.**

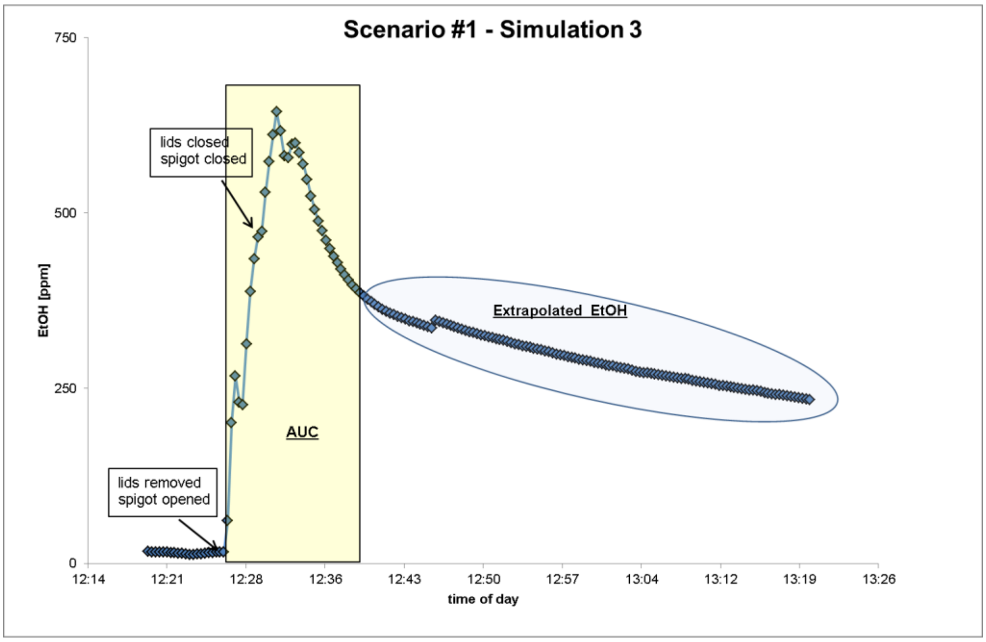

Fig. A 5: **Scenario # 1; Simulation 3 - time of day vs ethanol concentration plot. Data points used for the calculation of the AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) are marked by a yellow rectangle. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval.**

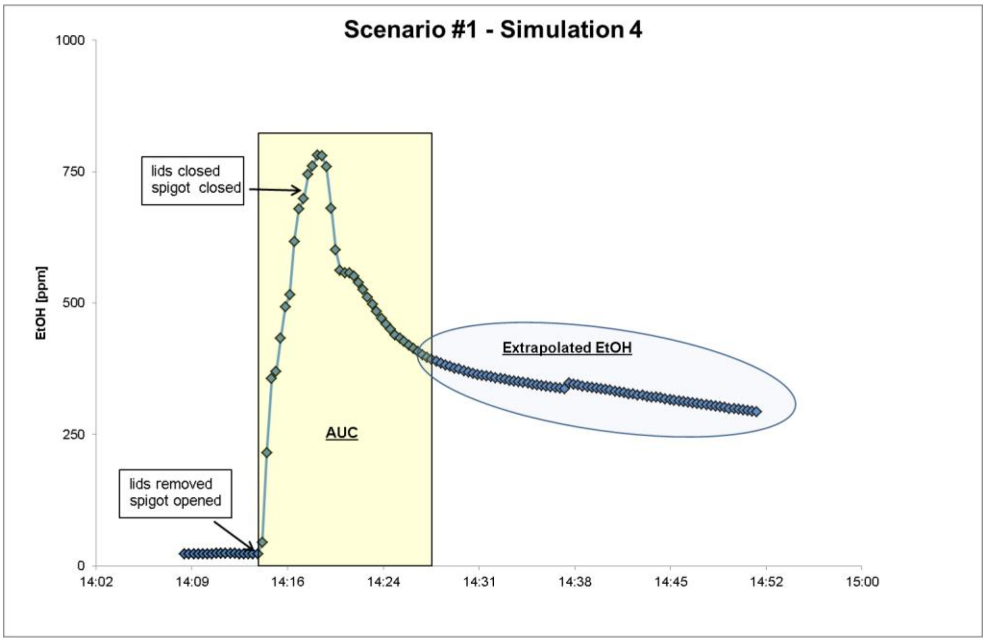

Fig. A 6: **Scenario # 1; Simulation 4 - time of day vs ethanol concentration plot. Data points used for the calculation of the AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) are marked by a yellow rectangle. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval.**

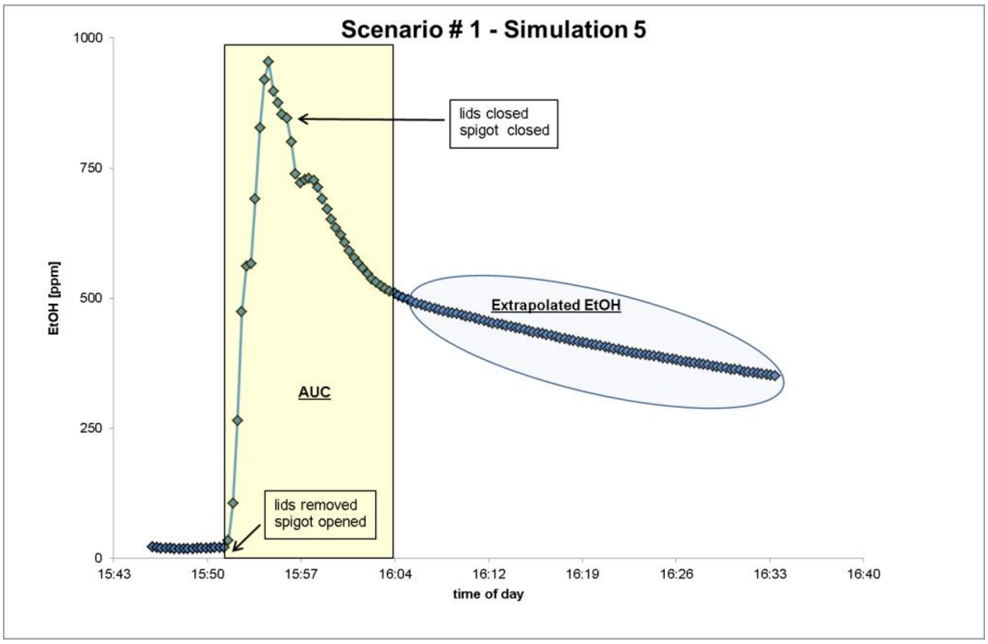

Fig. A 7: **Scenario # 1; Simulation 5 - time of day vs ethanol concentration plot. Data points used for the calculation of the AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) are marked by a yellow rectangle. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval.**

SCENARIO #2

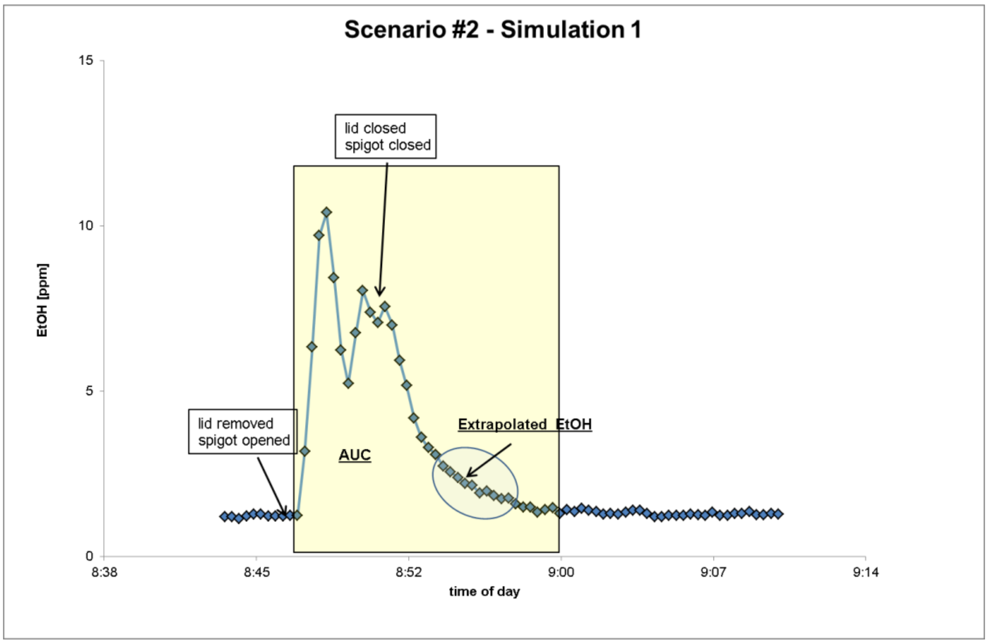

Fig. A 8: **Scenario # 2; Simulation 1 - time of day vs ethanol concentration plot. Data points used for the calculation of the AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) are marked by a yellow rectangle. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval.**

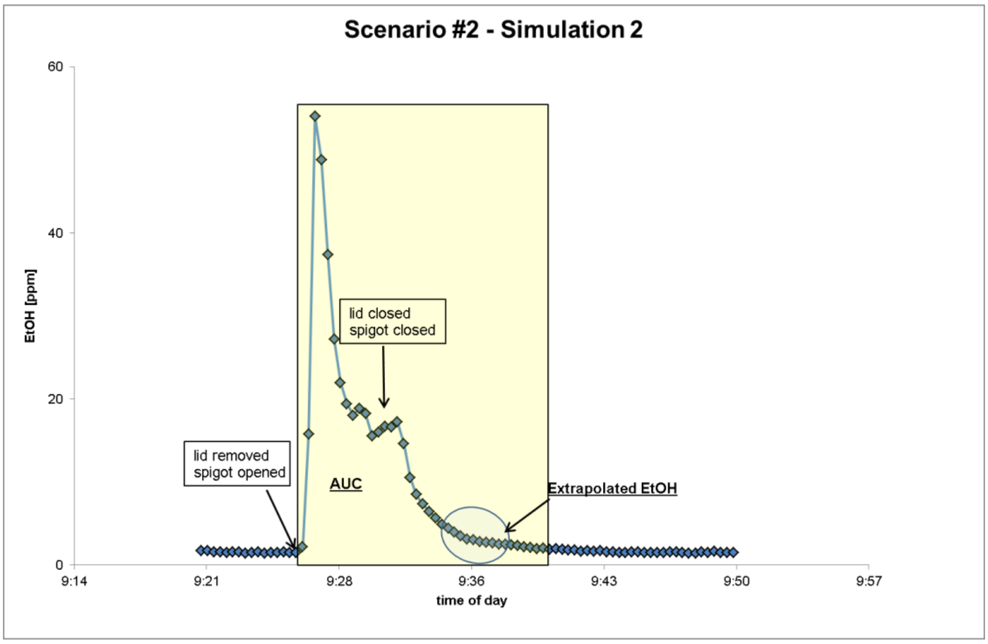

Fig. A 9: **Scenario # 2; Simulation 2 - time of day vs ethanol concentration plot. Data points used for the calculation of the AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) are marked by a yellow rectangle. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval.**

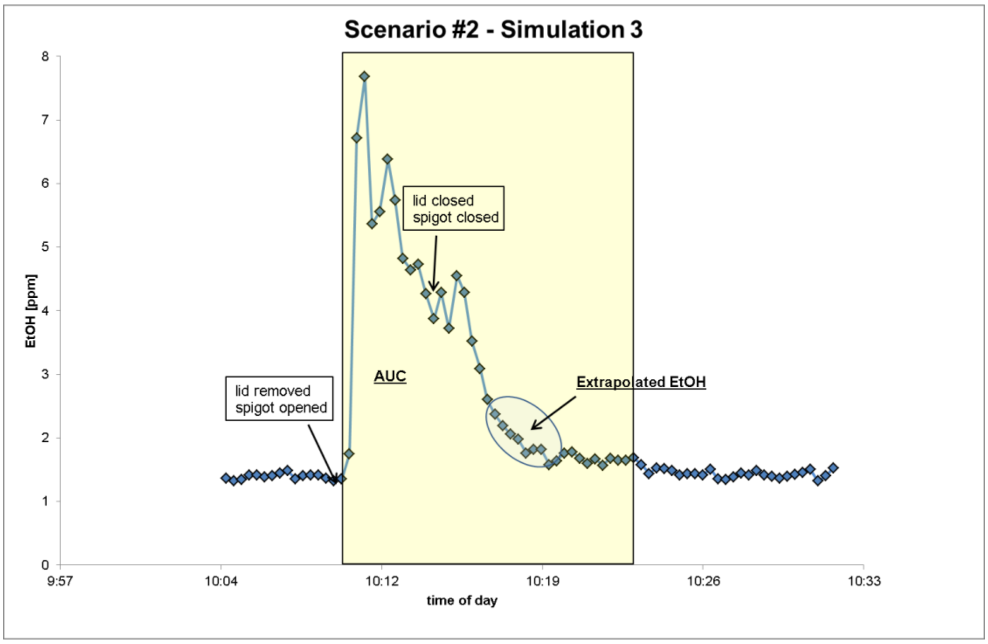

Fig. A 10: **Scenario # 2; Simulation 3 - time of day vs ethanol concentration plot. Data points used for the calculation of the AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) are marked by a yellow rectangle. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval.**

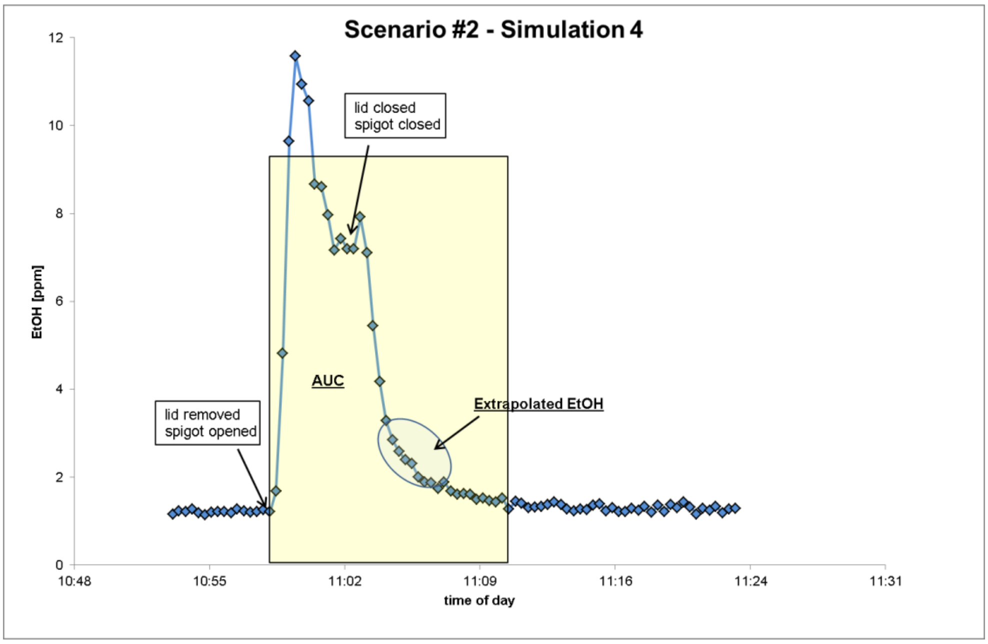

Fig. A 11: **Scenario # 2; Simulation 4 - time of day vs ethanol concentration plot. Data points used for the calculation of the AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) are marked by a yellow rectangle. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval.**

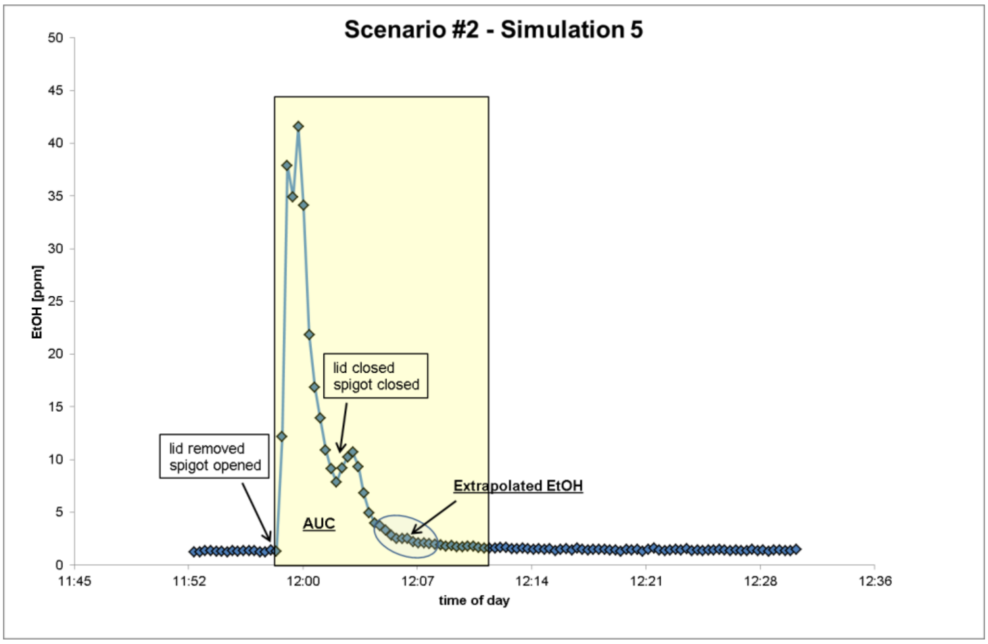

Fig. A 12: **Scenario # 2; Simulation 5 - time of day vs ethanol concentration plot. Data points used for the calculation of the AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) are marked by a yellow rectangle. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval.**

SCENARIO #3

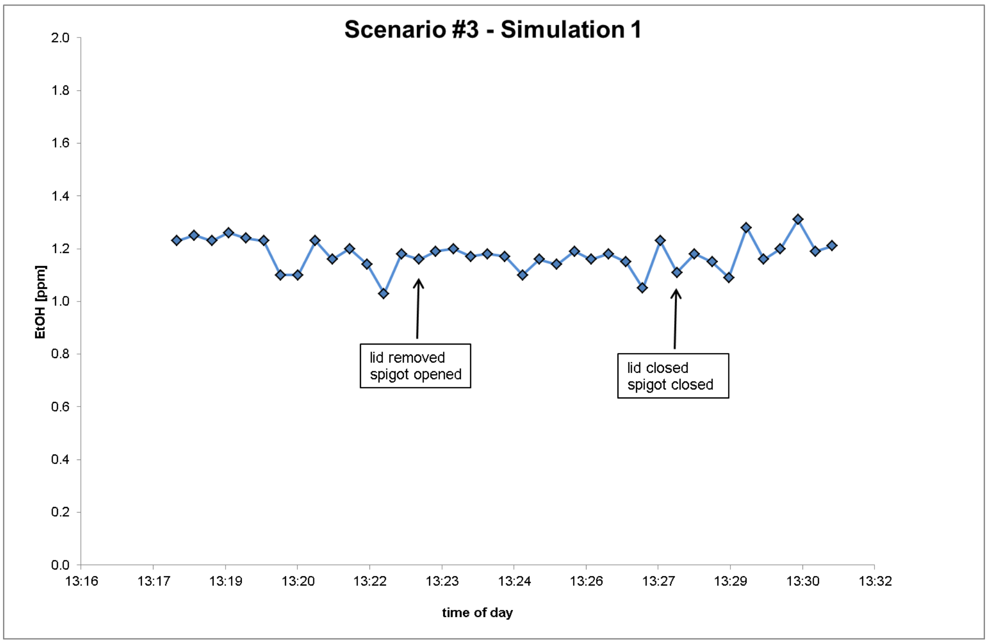

Fig. A 13: Scenario # 3; Simulation 1 - time of day vs ethanol concentration plot.

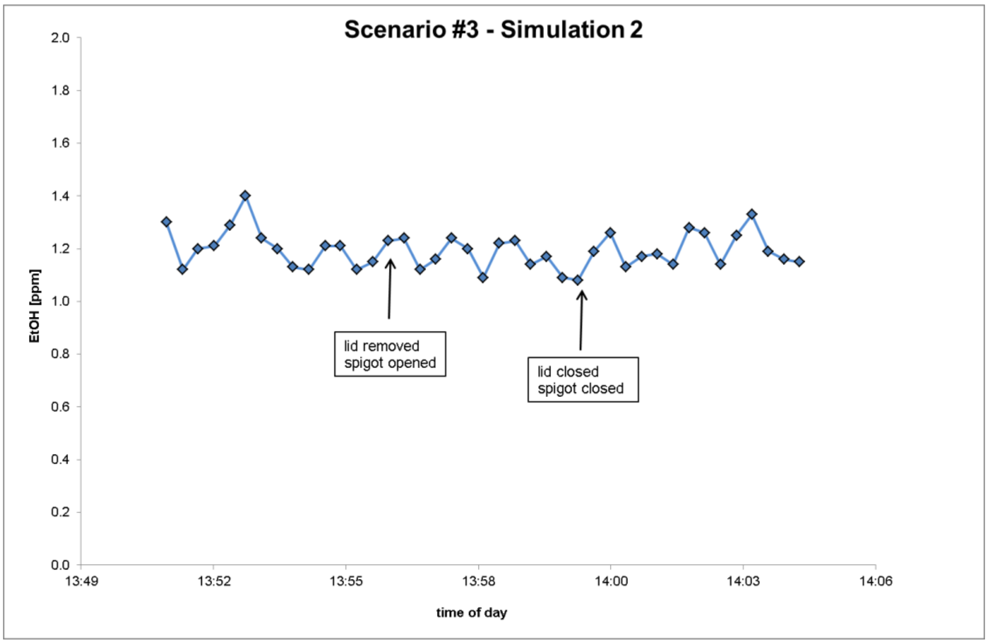

Fig. A 14: Scenario # 3; Simulation 2 - time of day vs ethanol concentration plot.

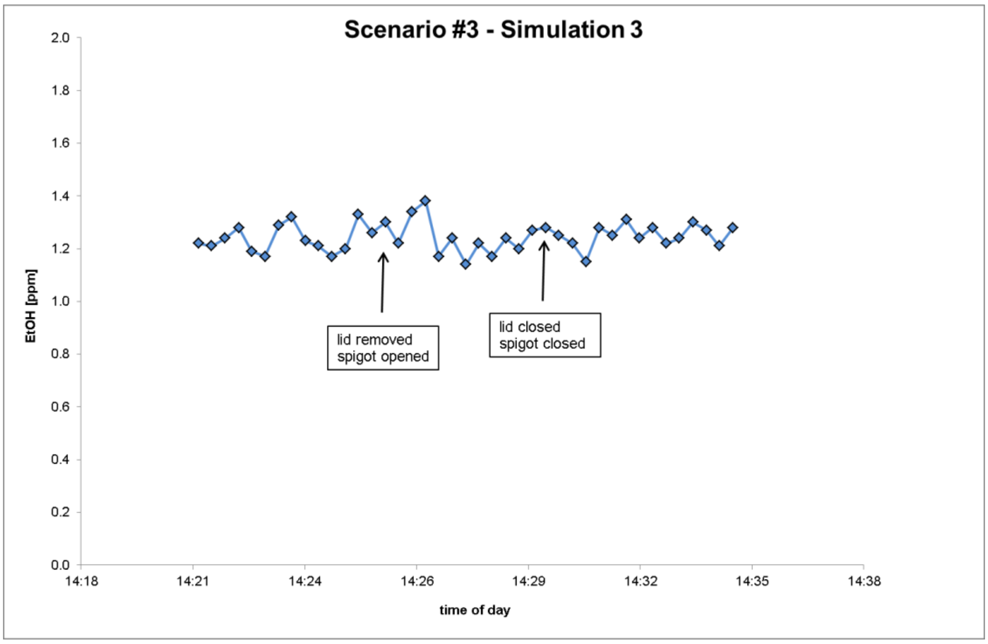

Fig. A 15: **Scenario # 3; Simulation 3 - time of day vs ethanol concentration plot.**

SCENARIO #4

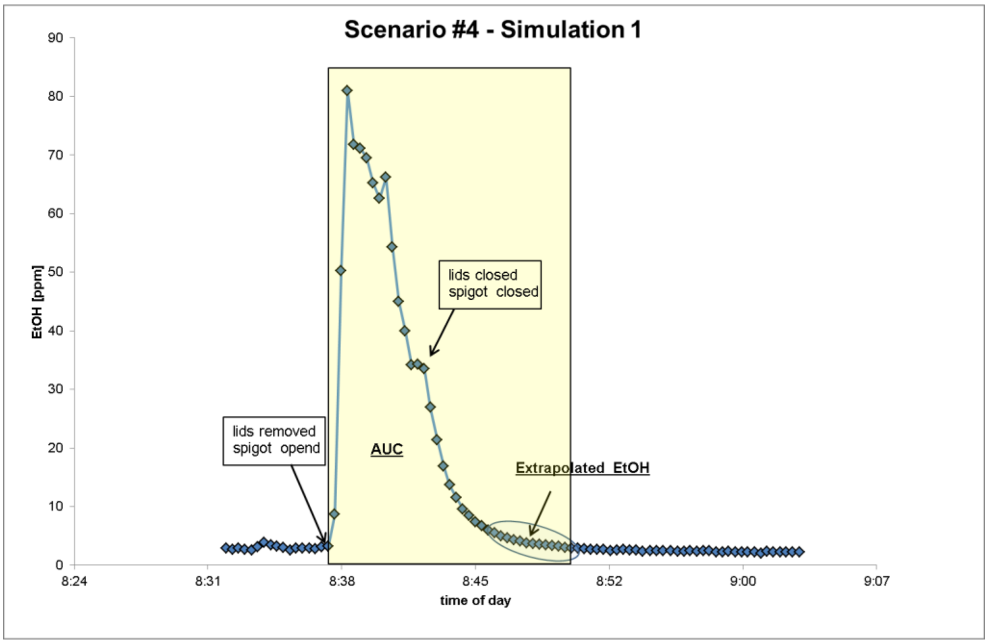

Fig. A 16: **Scenario # 4; Simulation 1 - time of day vs ethanol concentration plot. Data points used for the calculation of the AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) are marked by a yellow rectangle. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval.**

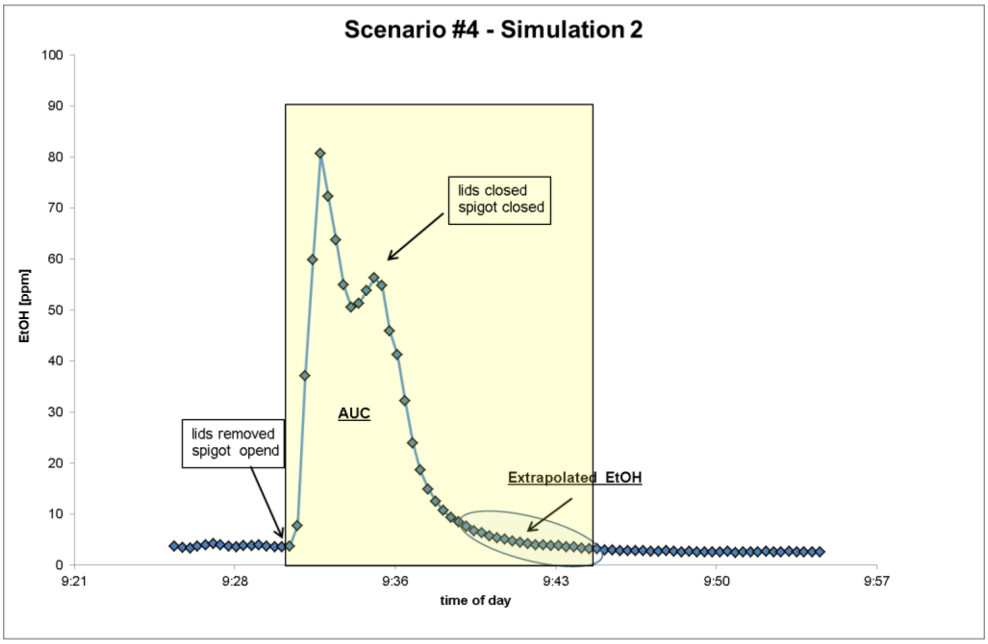

Fig. A 17: **Scenario # 4; Simulation 2 - time of day vs ethanol concentration plot. Data points used for the calculation of the AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) are marked by a yellow rectangle. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval.**

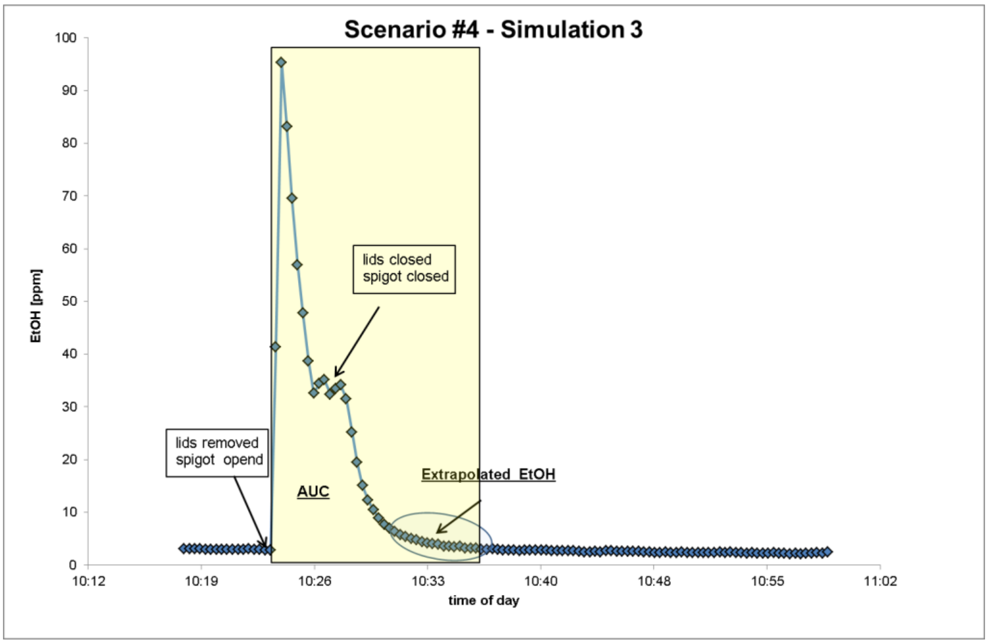

Fig. A 18: **Scenario # 4; Simulation 3 - time of day vs ethanol concentration plot. Data points used for the calculation of the AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) are marked by a yellow rectangle. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval.**

SCENARIO #5

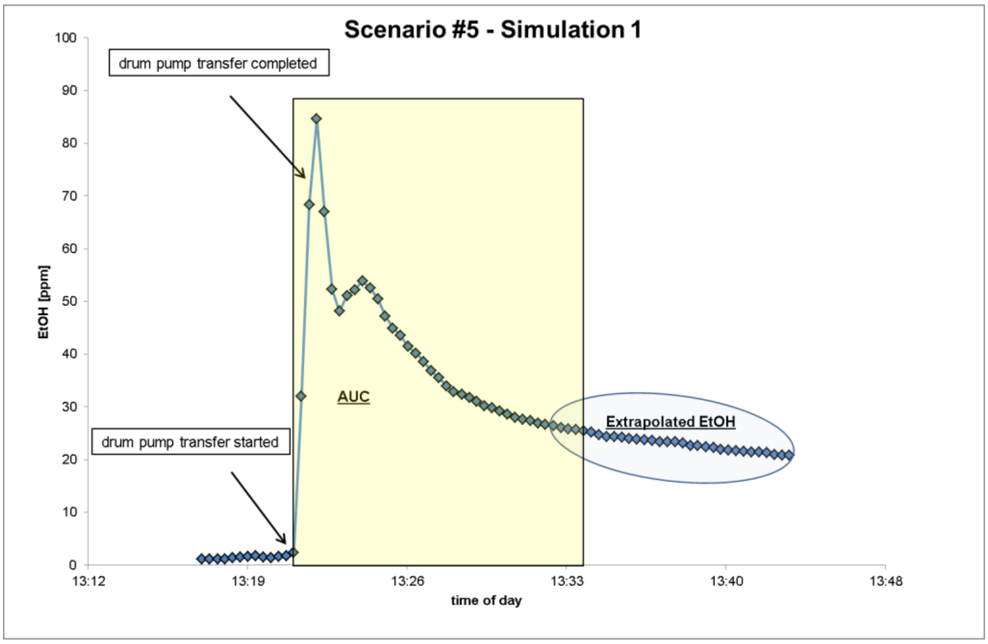

Fig. A 19: **Scenario # 5; Simulation 1 - time of day vs ethanol concentration plot. Data points used for the calculation of the AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) are marked by a yellow rectangle. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval.**

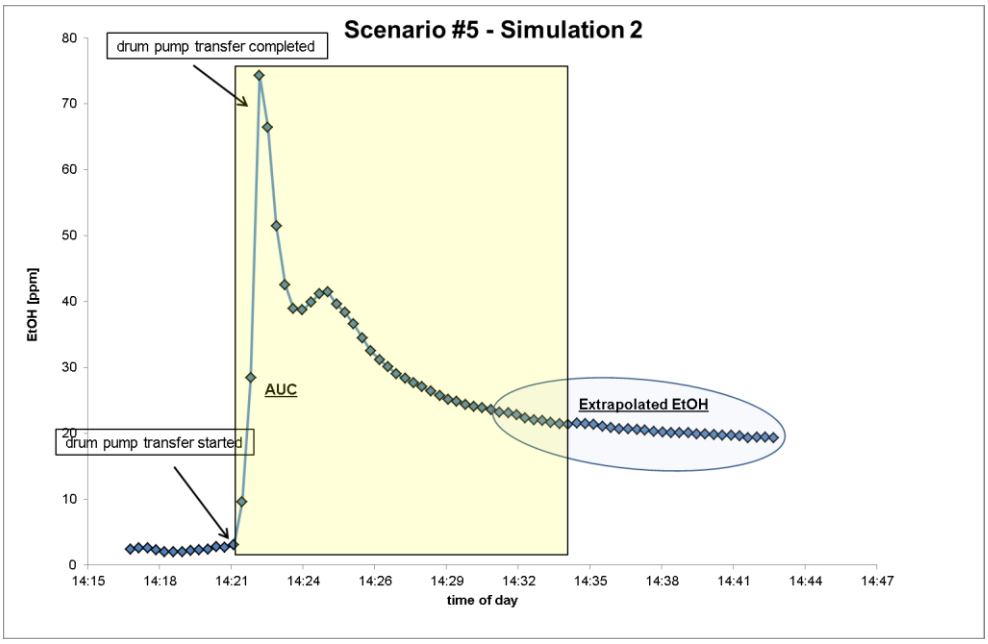

Fig. A 20: **Scenario # 5; Simulation 2 - time of day vs ethanol concentration plot. Data points used for the calculation of the AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) are marked by a yellow rectangle. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval.**

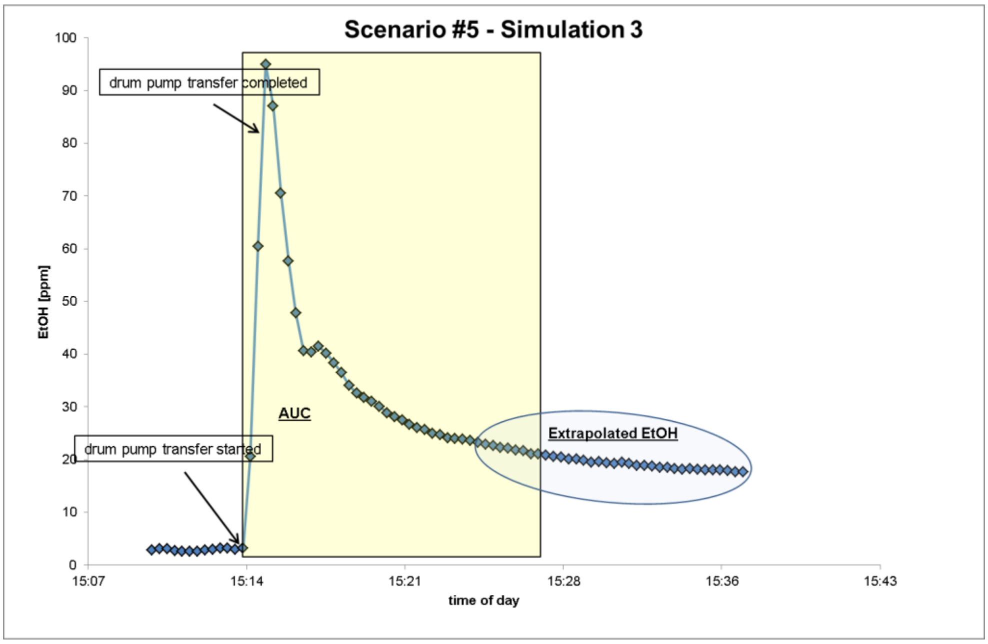

Fig. A 21: **Scenario # 5; Simulation 3 - time of day vs ethanol concentration plot. Data points used for the calculation of the AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) are marked by a yellow rectangle. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval.**

SCENARIO #6

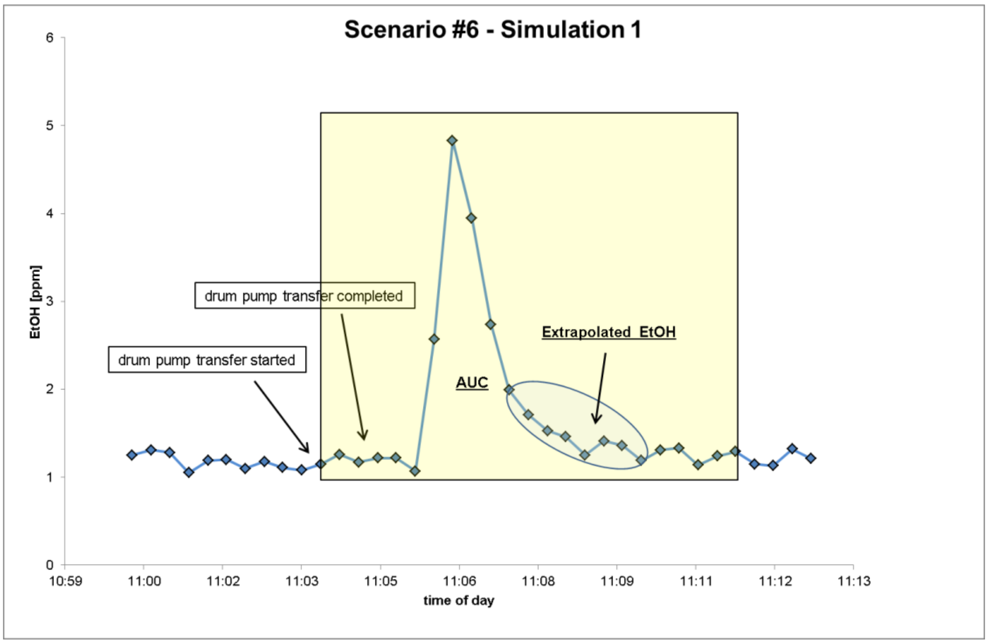

Fig. A 22: **Scenario # 6; Simulation 2 - time of day vs ethanol concentration plot. Data points used for the calculation of the AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) are marked by a yellow rectangle. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval.**

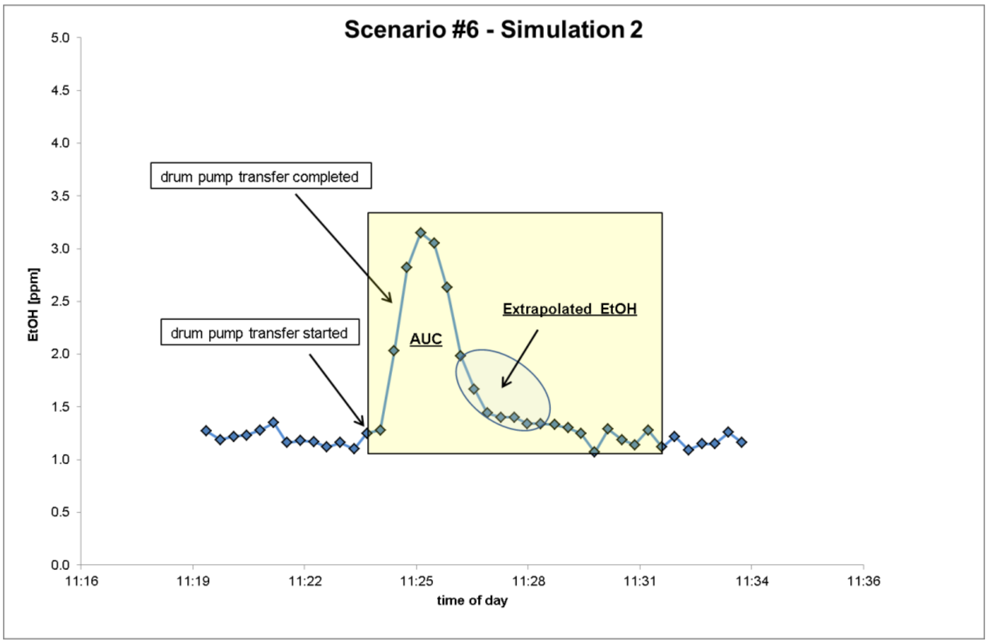

Fig. A 23: **Scenario # 6; Simulation 2 - time of day vs ethanol concentration plot. Data points used for the calculation of the AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) are marked by a yellow rectangle. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval.**

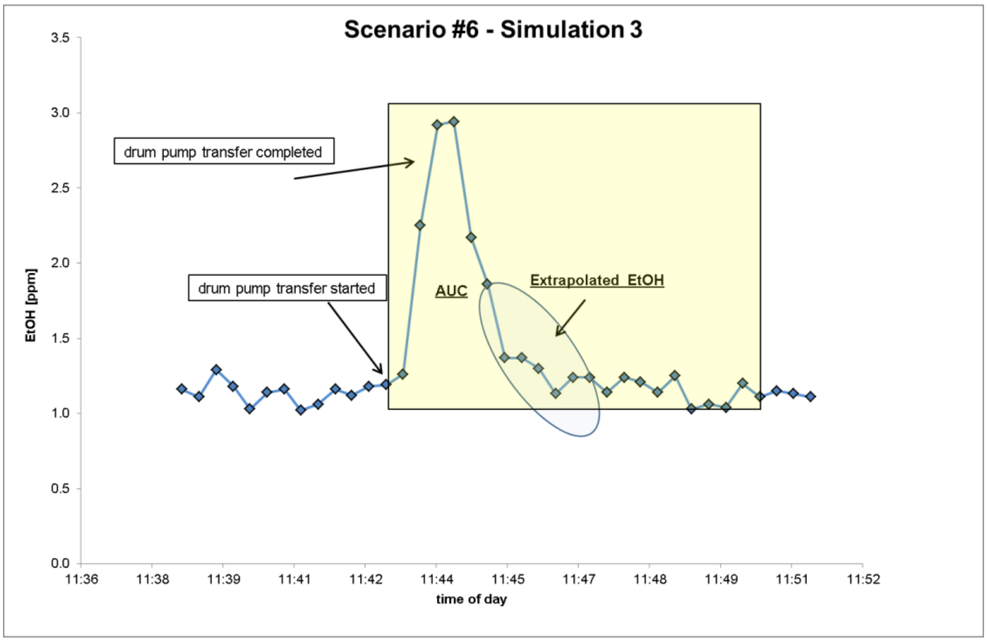

Fig. A 24: **Scenario # 6; Simulation 3 - time of day vs ethanol concentration plot. Data points used for the calculation of the AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) are marked by a yellow rectangle. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval.**

SCENARIO #7

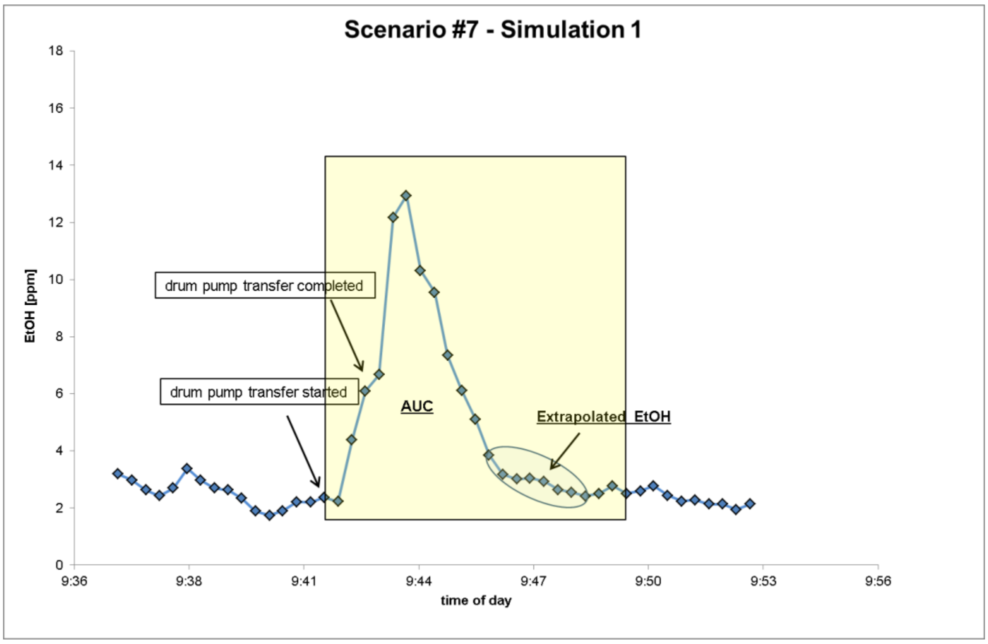

Fig. A 25: **Scenario # 7; Simulation 1 - time of day vs ethanol concentration plot. Data points used for the calculation of the AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) are marked by a yellow rectangle. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval.**

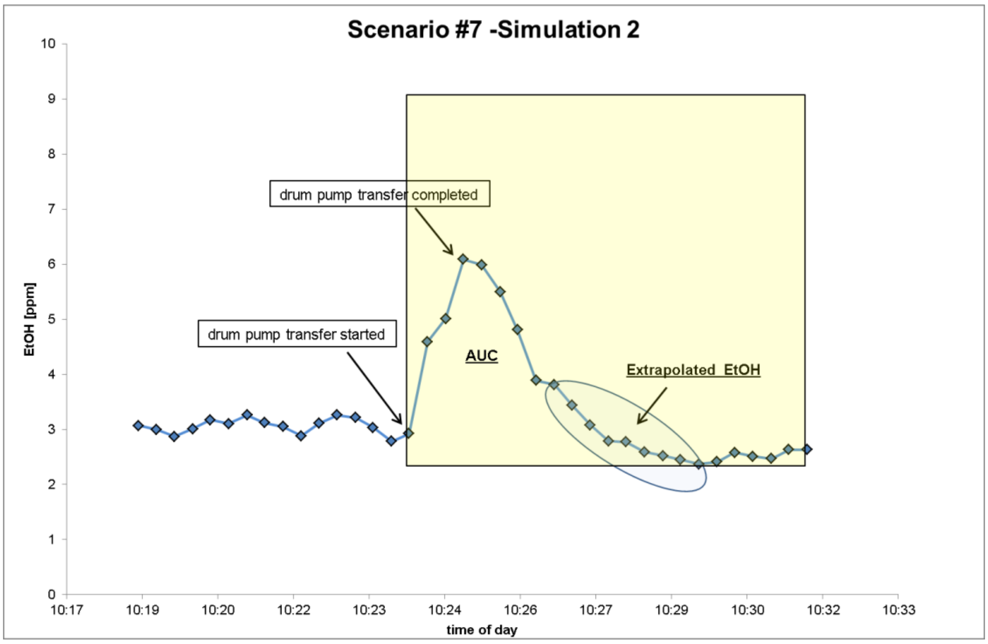

Fig. A 26: **Scenario # 7; Simulation 2 - time of day vs ethanol concentration plot. Data points used for the calculation of the AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) are marked by a yellow rectangle. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval.**

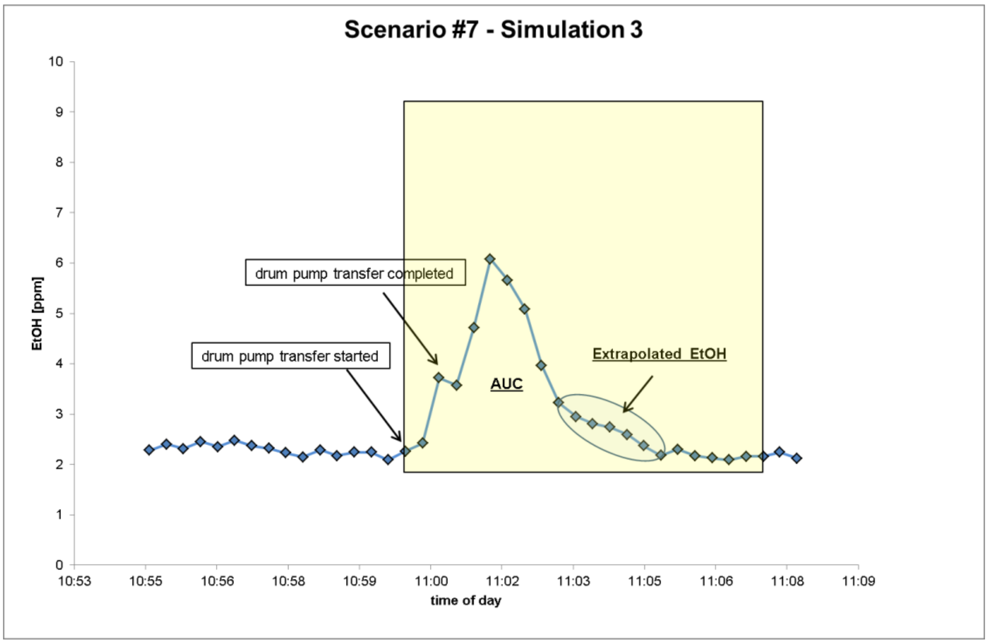

Fig. A 27: **Scenario # 7; Simulation 3 - time of day vs ethanol concentration plot. Data points used for the calculation of the AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) are marked by a yellow rectangle. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval.**

SCENARIO #7A

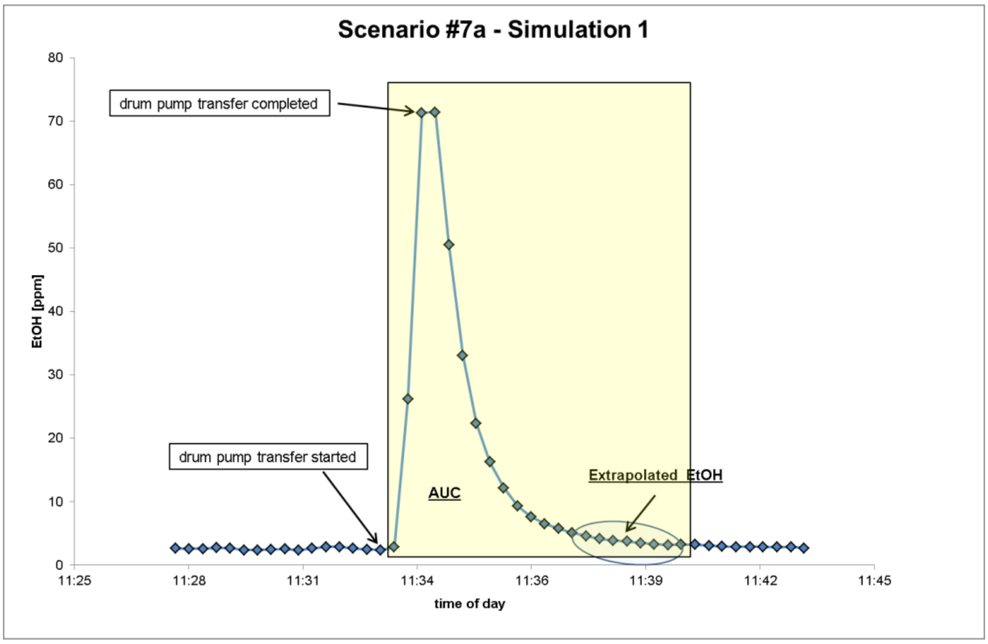

Fig. A 28: **Scenario # 7a; Simulation 1 - time of day vs ethanol concentration plot. Data points used for the calculation of the AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) are marked by a yellow rectangle. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval.**

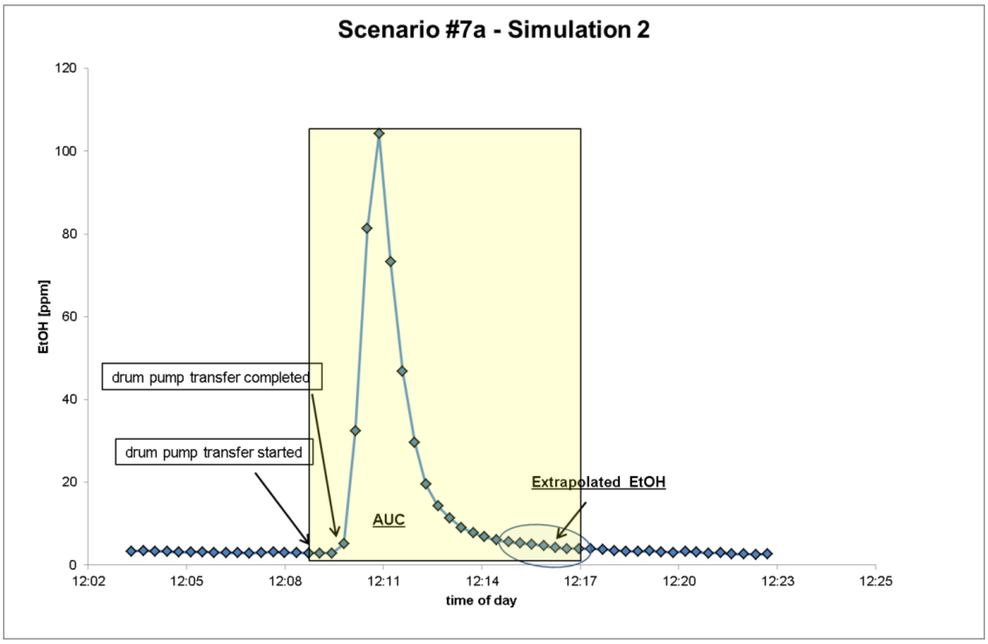

Fig. A 29: **Scenario # 7a; Simulation 2 - time of day vs ethanol concentration plot. Data points used for the calculation of the AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) are marked by a yellow rectangle. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval.**

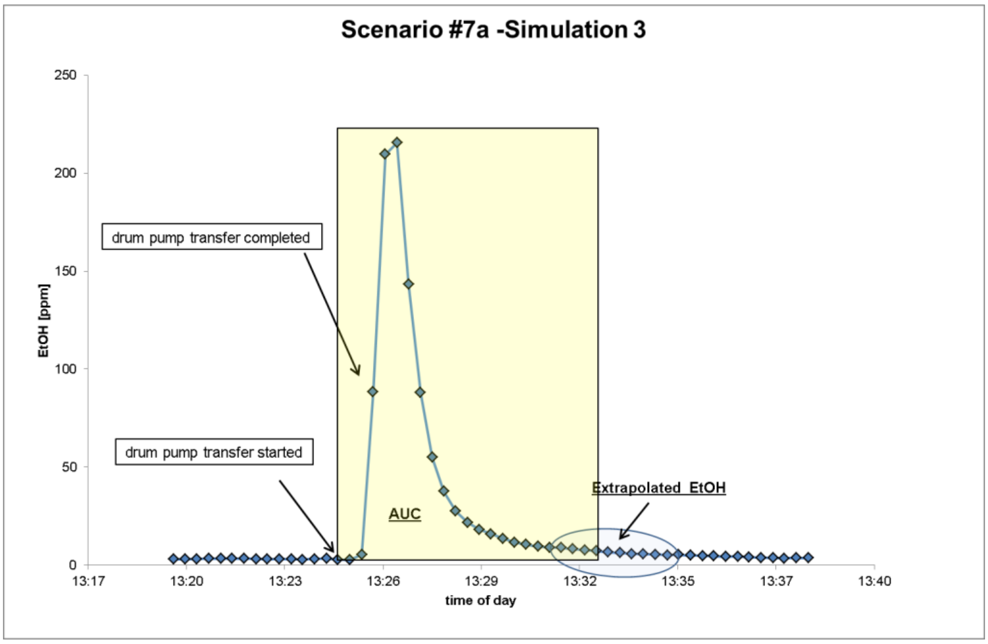

Fig. A 30: **Scenario # 7a; Simulation 3 - time of day vs ethanol concentration plot. Data points used for the calculation of the AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) are marked by a yellow rectangle. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval.**

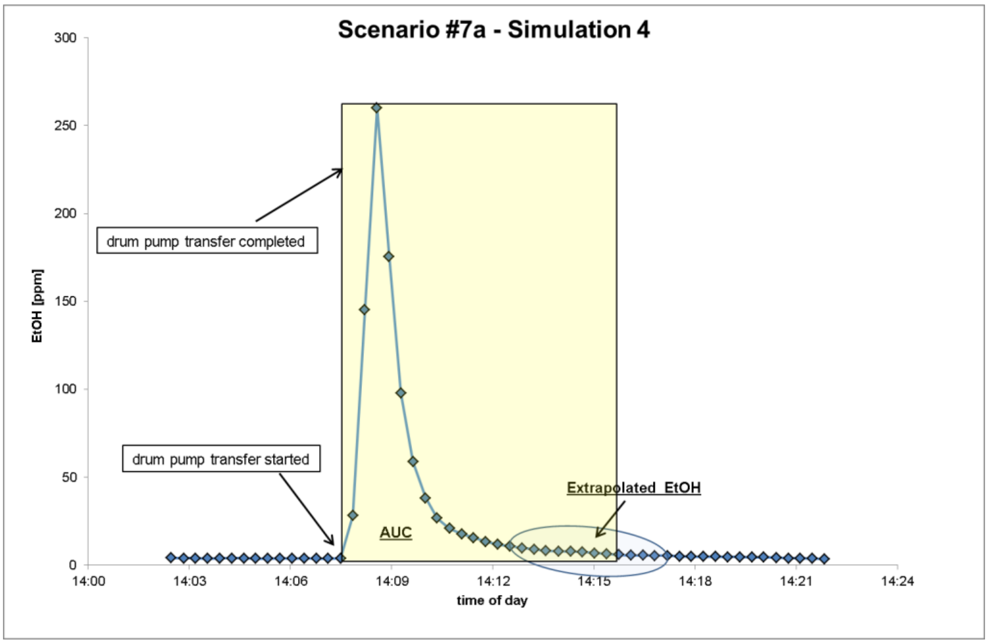

Fig. A 31: **Scenario # 7a; Simulation 4 - time of day vs ethanol concentration plot. Data points used for the calculation of the AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) are marked by a yellow rectangle. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval.**

SCENARIO #8

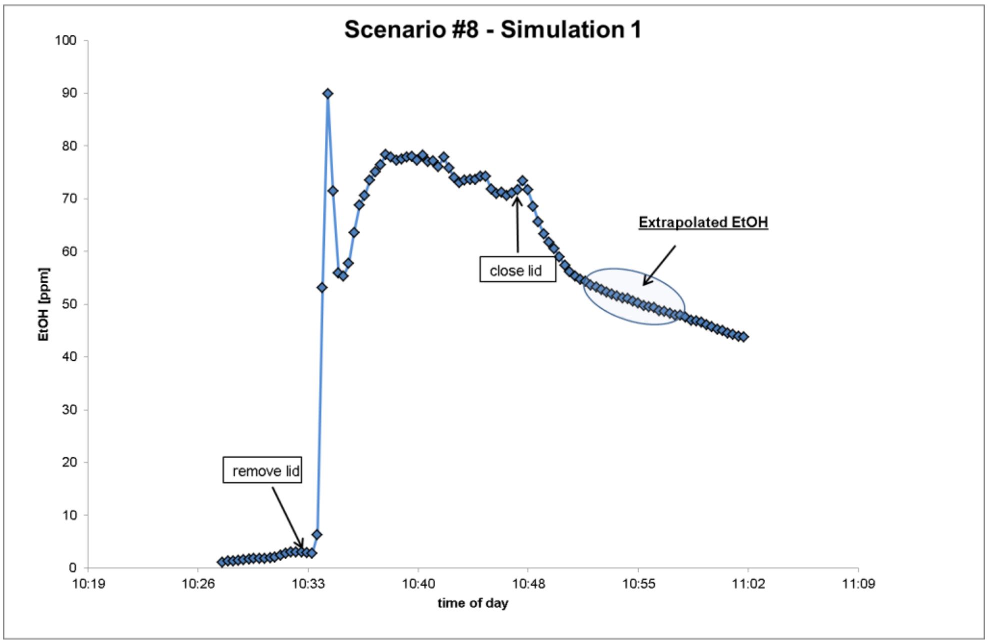

Fig. A 32: **Scenario # 8; Simulation 1 - time of day vs ethanol concentration plot. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval. The AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) was not calculated due to changed exposure pattern (development of a plateau) compared to gravity and drum pump transfer scenarios.**

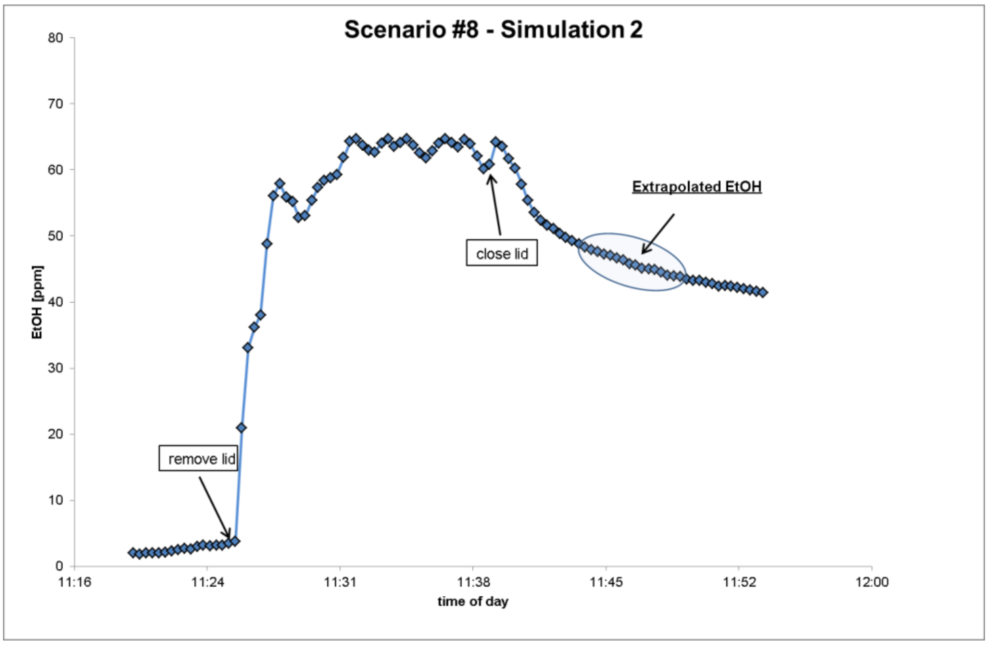

Fig. A 33: **Scenario # 8; Simulation 2 - time of day vs ethanol concentration plot. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval. The AUC (= measure for the total amount of ethanol measured at the**

sampling probe within a given time window) was not calculated due to changed exposure pattern (development of a plateau) compared to gravity and drum pump transfer scenarios.

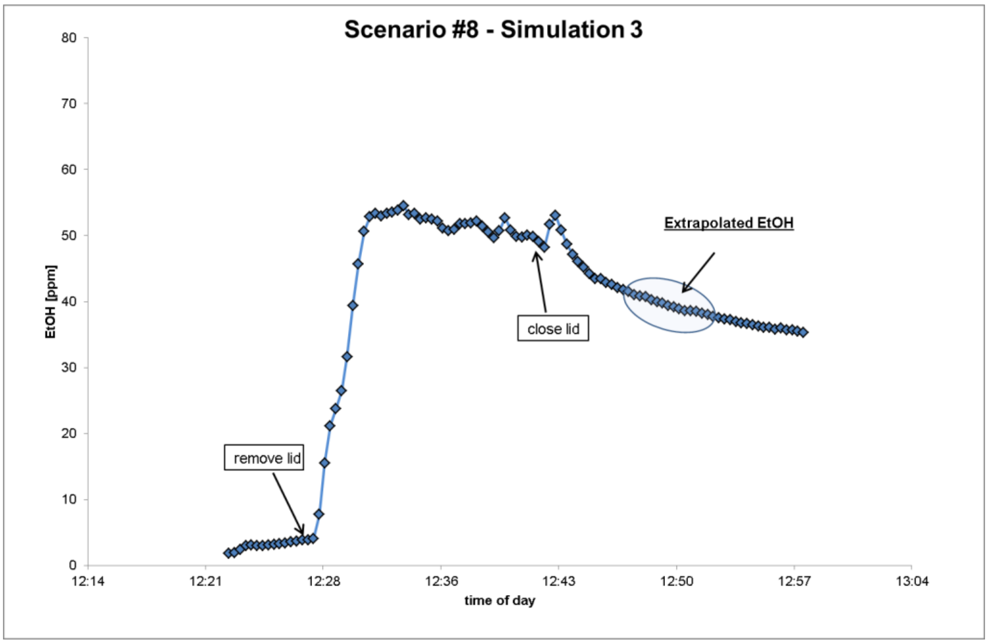

Fig. A 34: Scenario # 8; Simulation 3 - time of day vs ethanol concentration plot. Data points used to calculate the extrapolated ethanol concentration are circled by a blue oval. The AUC (= measure for the total amount of ethanol measured at the sampling probe within a given time window) was not calculated due to changed exposure pattern (development of a plateau) compared to gravity and drum pump transfer scenarios.

SCENARIO #9

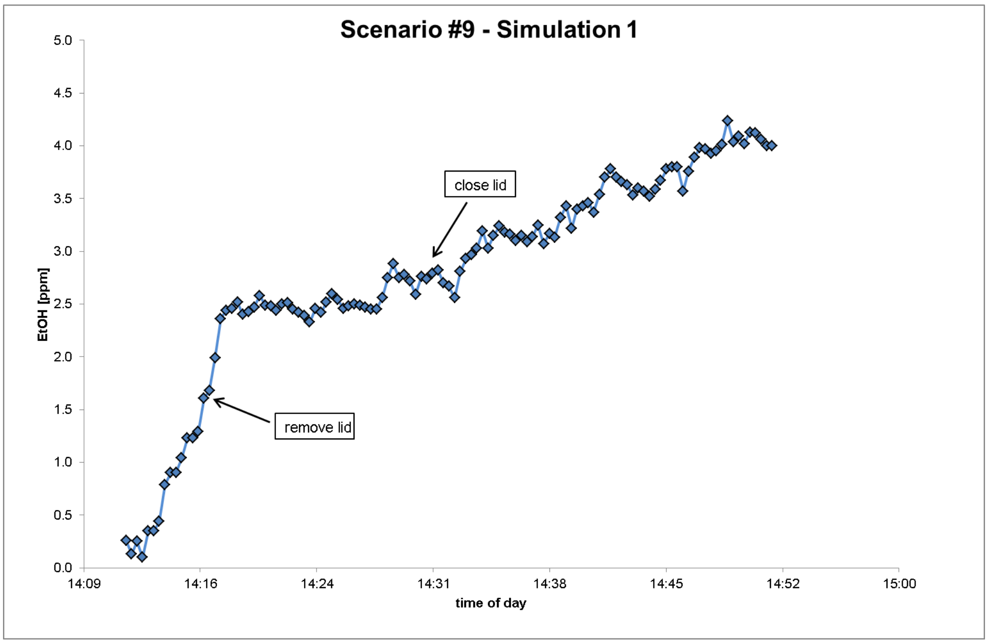

Fig. A 35: Scenario # 9; Simulation 1 - time of day vs ethanol concentration plot.

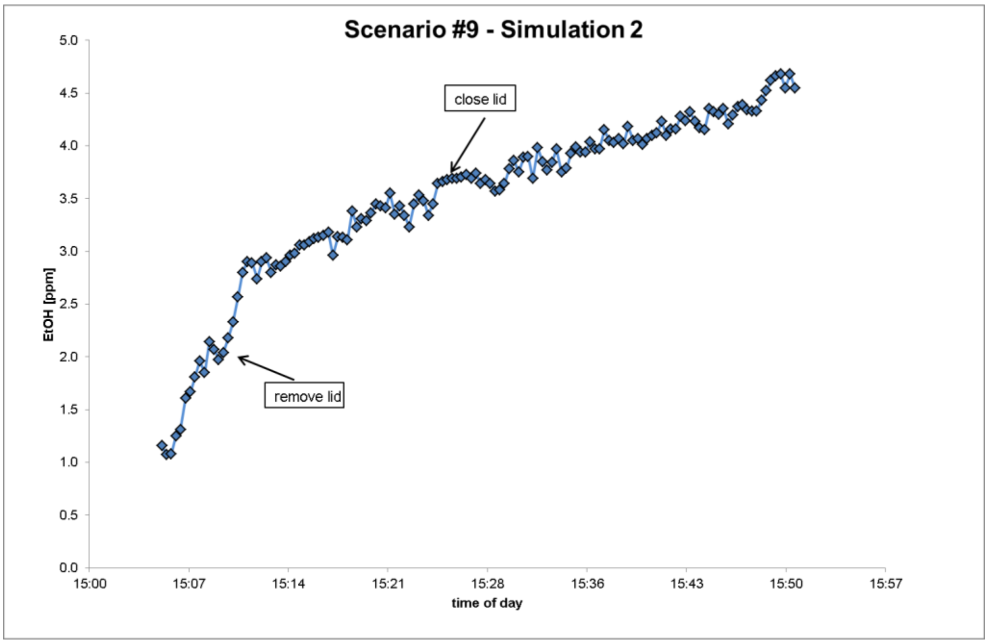

Fig. A 36: **Scenario # 9; Simulation 2 - time of day vs ethanol concentration plot.**

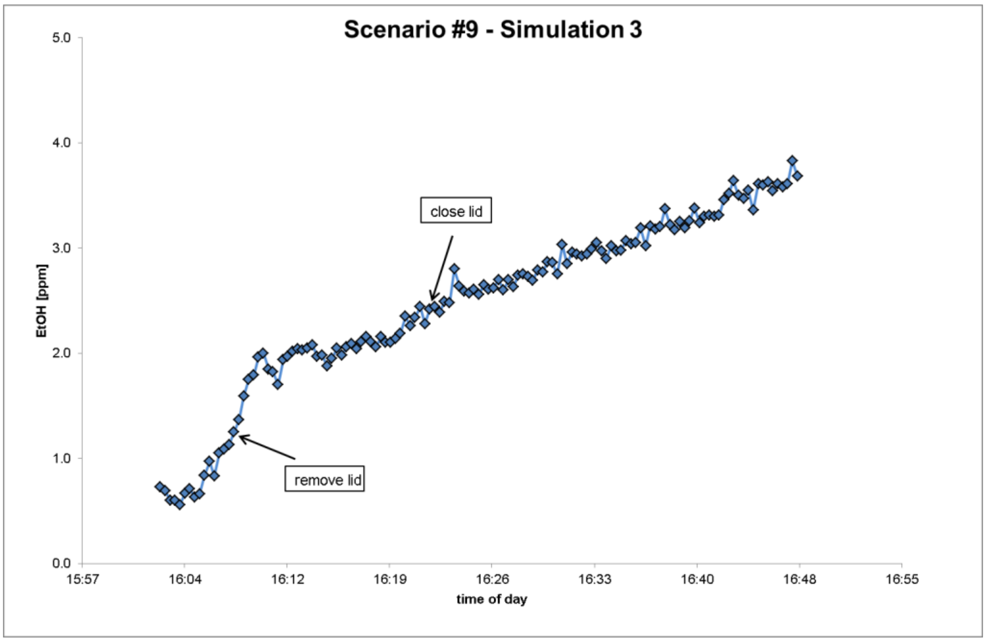

Fig. A 37: **Scenario # 9; Simulation 3 - time of day vs ethanol concentration plot.**

EXTRAPOLATION OF ETHANOL CONCENTRATIONS

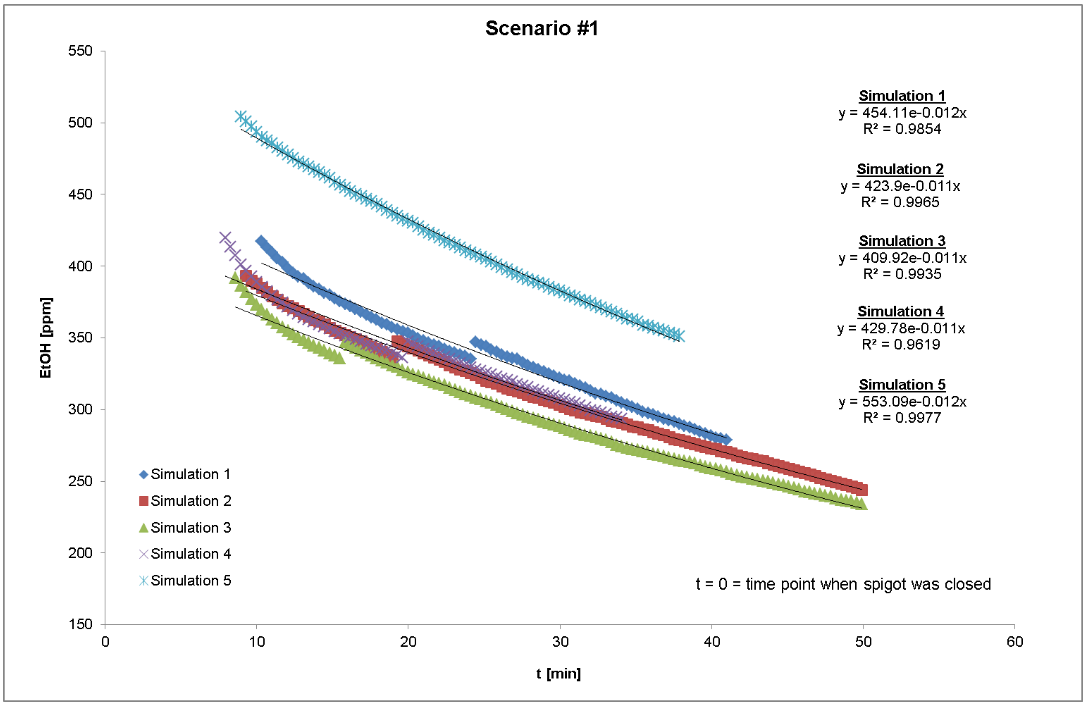

Fig. A 38: **Scenario #1 – Fitted data points for the determination of the extrapolated ethanol concentration. Trendline: y = y_0 exp(-kt); with y_0 being the extrapolated ethanol concentration and k*60 min being the air exchange rate.**

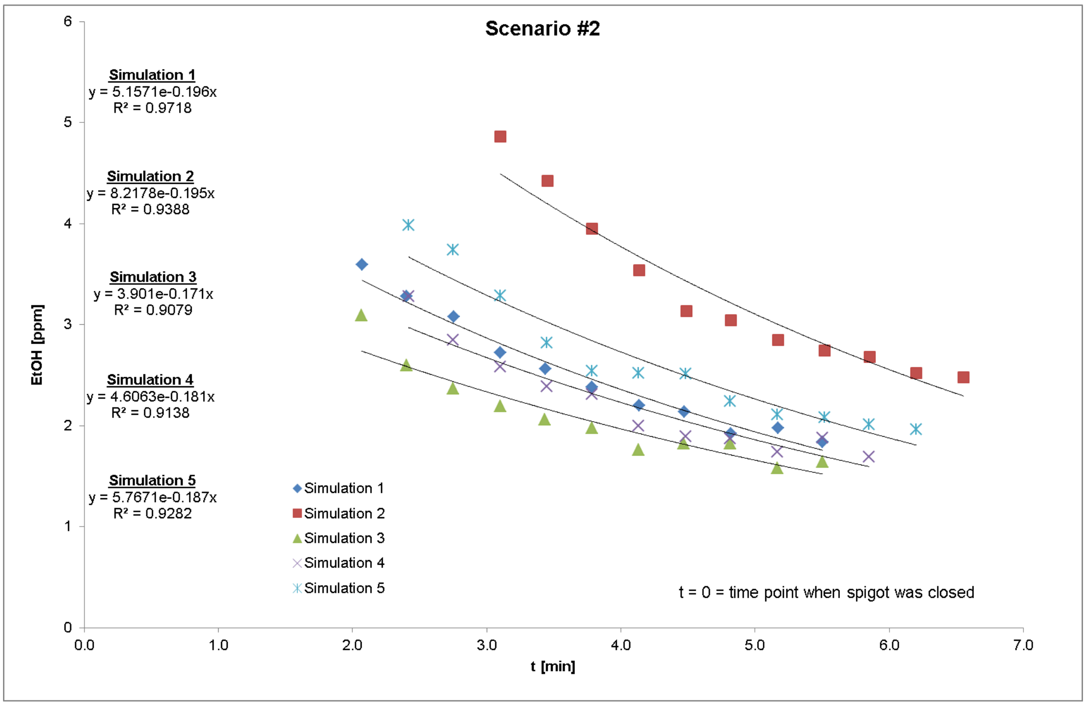

Fig. A 39: **Scenario #2 – Fitted data points for the determination of the extrapolated ethanol concentration. Trendline: y = y_0 exp(-kt); with y_0 being the extrapolated ethanol concentration and k*60 min being the air exchange rate.**

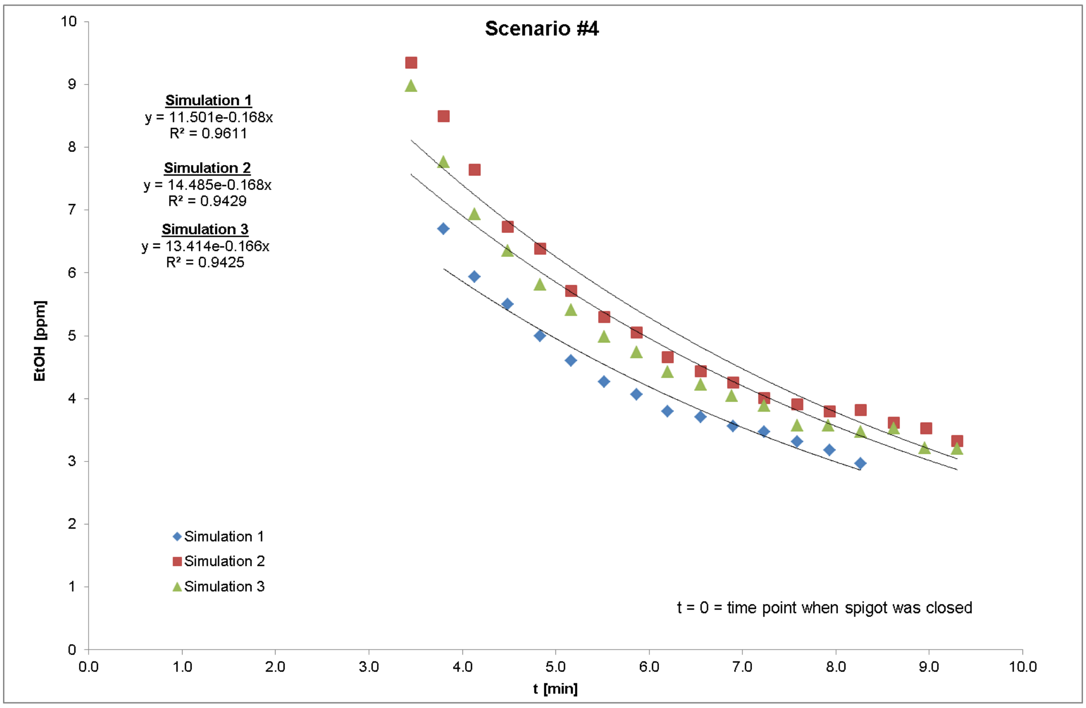

Fig. A 40: **Scenario #4 – Fitted data points for the determination of the extrapolated ethanol concentration. Trendline: $y = y_0 \exp(-kt)$; with y_0 being the extrapolated ethanol concentration and k*60 min being the air exchange rate.**

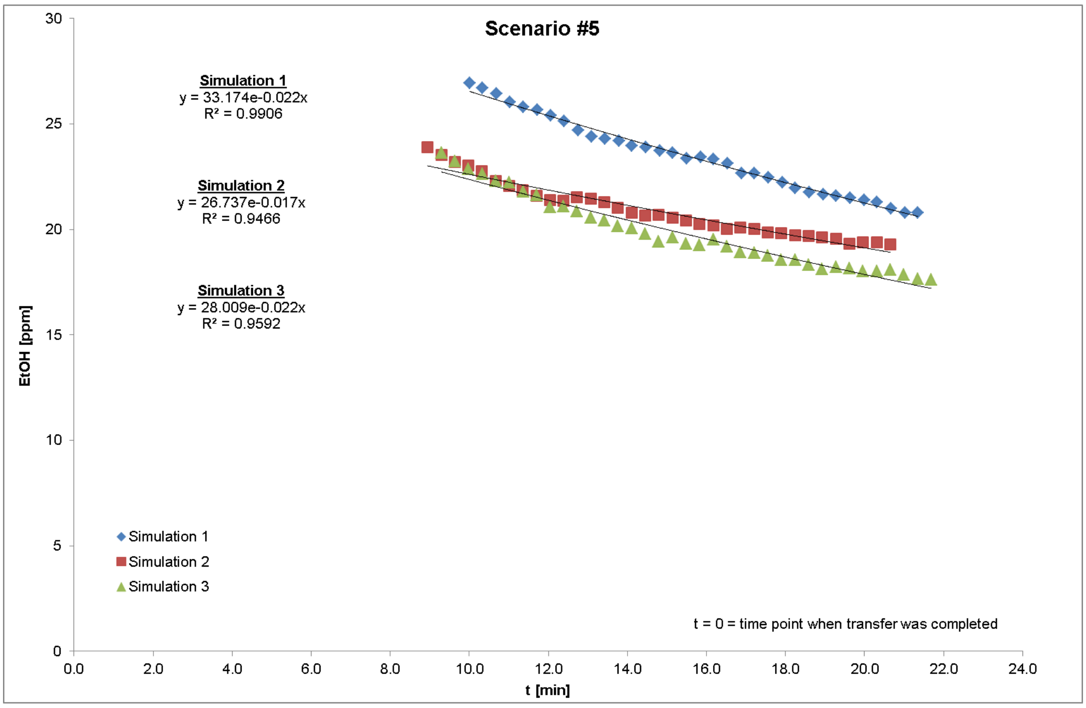

Fig. A 41: **Scenario #5 – Fitted data points for the determination of the extrapolated ethanol concentration. Trendline: $y = y_0 \exp(-kt)$; with y_0 being the extrapolated ethanol concentration and k*60 min being the air exchange rate.**

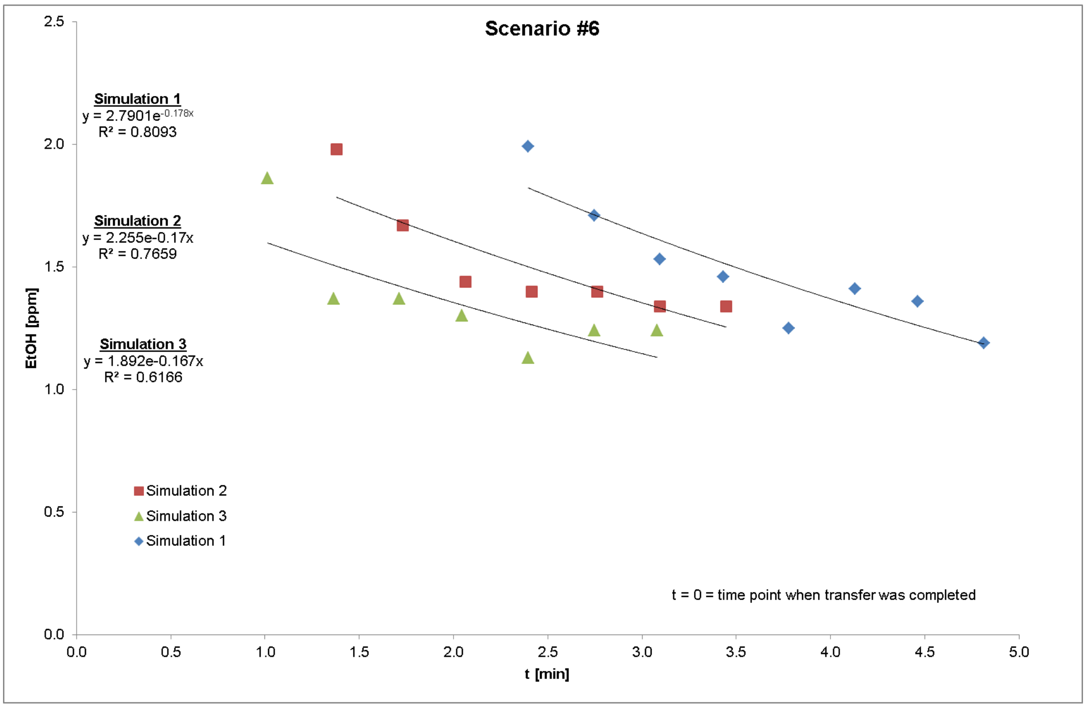

Fig. A 42: **Scenario #6 – Fitted data points for the determination of the extrapolated ethanol concentration. Trendline: y = y_0 exp(-kt); with y_0 being the extrapolated ethanol concentration and k*60 min being the air exchange rate.**

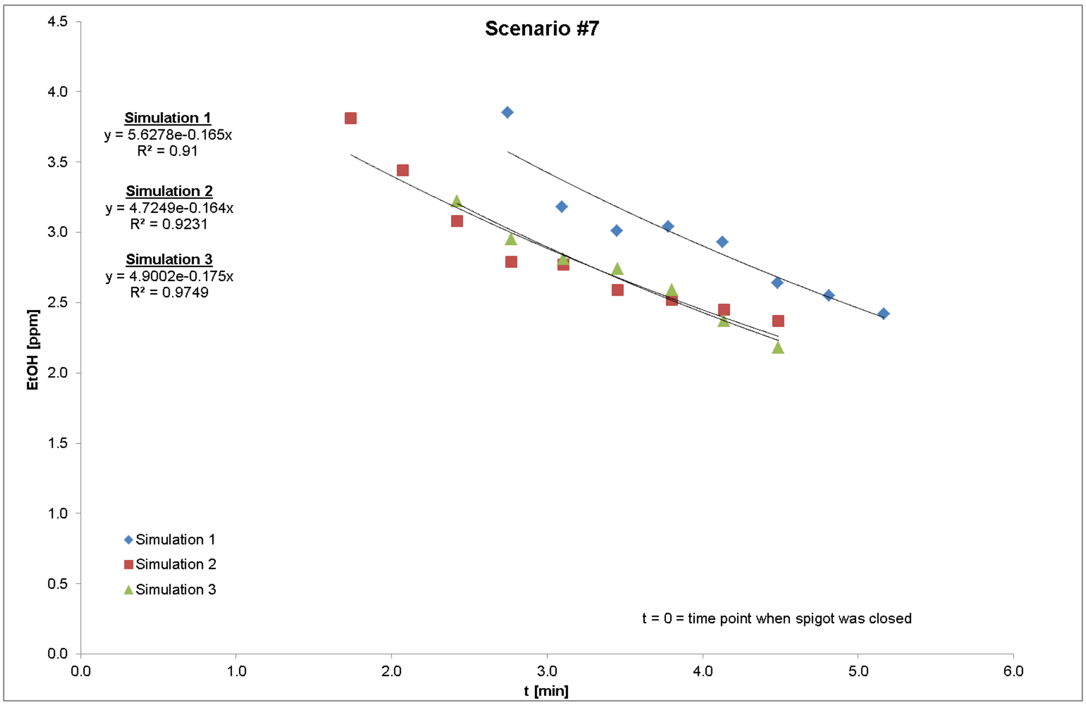

Fig. A 43: **Scenario #7 – Fitted data points for the determination of the extrapolated ethanol concentration. Trendline: y = y_0 exp(-kt); with y_0 being the extrapolated ethanol concentration and k*60 min being the air exchange rate.**

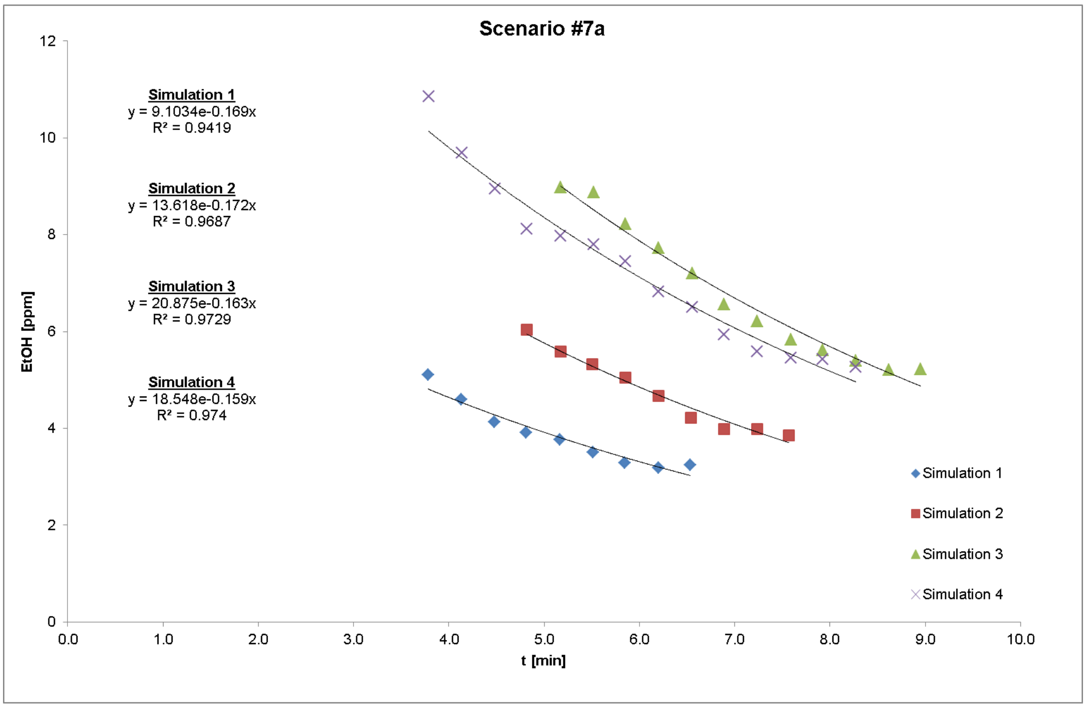

Fig. A 44: **Scenario #7a – Fitted data points for the determination of the extrapolated ethanol concentration. Trendline: $y = y_0 \exp(-kt)$; with y_0 being the extrapolated ethanol concentration and k*60 min being the air exchange rate.**

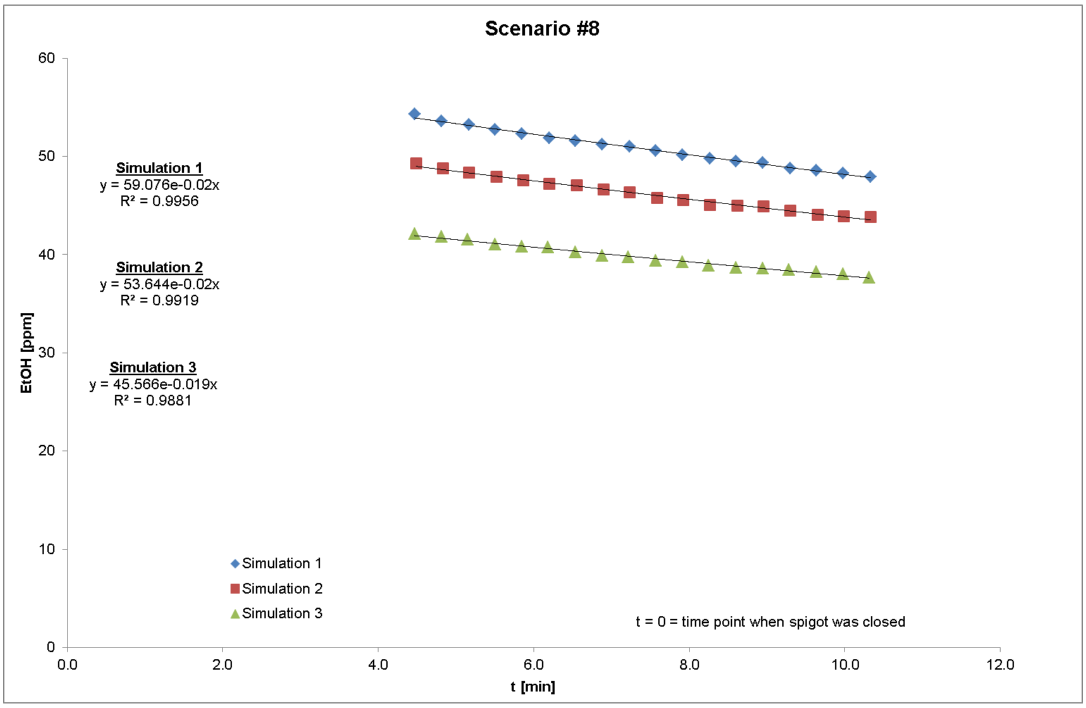

Fig. A 45: **Scenario #8 – Fitted data points for the determination of the extrapolated ethanol concentration. Trendline: $y = y_0 \exp(-kt)$; with y_0 being the extrapolated ethanol concentration and k*60 min being the air exchange rate.**

DATA OVERVIEW

Table 26: Effectiveness of Scenario #2 in comparison to baseline scenario #1.

Scenario #1						
Simulation #	**background EtOH [ppm]**	**peak EtOH [ppm]**	**extrapol. EtOH [ppm]**	**AUC* [ppm*min]**	**AUC time intervall [min]**	**air exchange rate [h^{-1}]**
1	22	850	454	6963	13	1.04
2	14	873	424	6601	13	0.95
3	15	645	410	5554	13	0.95
4	23	782	430	6502	13	0.95
5	20	953	553	7964	13	1.04
MV	**19**	**820**	**454**	**6717**	**13**	**1.0**
STDEV	**4**	**104**	**51**	**778**	**0.0**	**0.0**
rel. STDEV [%]	**20**	**13**	**11**	**12**	**0.1**	**4**
Scenario #2						
Simulation #	**background EtOH [ppm]**	**peak EtOH [ppm]**	**extrapol. EtOH [ppm]**	**AUC* [ppm*min]**	**AUC time intervall [min]**	**air exchange rate [h^{-1}]**
1	1	10	5	52	13	17
2	2	54	8	159	13	17
3	1	8	4	42	13	15
4	1	12	5	58	13	16
5	1	42	6	117	13	16
MV	**1**	**25**	**6**	**86**	**13**	**16.2**
STDEV	**0**	**19**	**1**	**45**	**0.0**	**0.7**
rel. STDEV [%]	**10**	**76**	**27**	**53**	**0.0**	**5**
Minimum exposure reduction [%]	**NA**	**91.6**	**98.0**	**97.1**	**NA**	**NA**
Maximum exposure reduction [%]	**NA**	**99.2**	**99.3**	**99.5**	**NA**	**NA**
Mean exposure reduction [%]	**NA**	**96.9**	**98.8**	**98.7**	**NA**	**NA**

* AUC = measure of the total amount of ethanol measured at sampling probe over a time interval of 13 min after opening spigot.

Table 27: Effectiveness of Scenario #4 in comparison to baseline scenario #1.

Scenario #1						
Simulation #	**background EtOH [ppm]**	**peak EtOH [ppm]**	**extrapol. EtOH [ppm]**	**AUC* [ppm*min]**	**AUC time intervall [min]**	**air exchange rate [h^{-1}]**
1	22	850	454	6963	13	1.04
2	14	873	424	6601	13	0.95
3	15	645	410	5554	13	0.95
4	23	782	430	6502	13	0.95
5	20	953	553	7964	13	1.04
MV	**19**	**820**	**454**	**6717**	**13**	**1.0**
STDEV	**4**	**104**	**51**	**778**	**0.0**	**0.0**
rel. STDEV [%]	**20**	**13**	**11**	**12**	**0.1**	**4**
Scenario #4						
Simulation #	**background EtOH [ppm]**	**peak EtOH [ppm]**	**extrapol. EtOH [ppm]**	**AUC* [ppm*min]**	**AUC time intervall [min]**	**air exchange rate [h^{-1}]**
1	3	81	12	333	13	15
2	4	81	14	323	13	15
3	3	95	13	289	13	14
MV	**3**	**86**	**13**	**315**	**13**	**14**
STDEV	**0**	**7**	**1**	**19**	**0**	**0**
rel. STDEV [%]	**11**	**8**	**9**	**6**	**0**	**0**
Minimum exposure reduction [%]	**NA**	**85.2**	**96.5**	**94.0**	**NA**	**NA**
Maximum exposure reduction [%]	**NA**	**91.5**	**97.9**	**96.4**	**NA**	**NA**
Mean exposure reduction [%]	**NA**	**89.6**	**97.1**	**95.3**	**NA**	**NA**

* AUC = measure of the total amount of ethanol measured at sampling probe over a time interval of 13 min after opening spigot.

Table 28: Effectiveness of Scenario #5 in comparison to baseline scenario #1.

Scenario #1						
Simulation #	**background EtOH [ppm]**	**peak EtOH [ppm]**	**extrapol. EtOH [ppm]**	**AUC* [ppm*min]**	**AUC time intervall [min]**	**air exchange rate [h^{-1}]**
1	22	850	454	6963	13	1.04
2	14	873	424	6601	13	0.95
3	15	645	410	5554	13	0.95
4	23	782	430	6502	13	0.95
5	20	953	553	7964	13	1.04
MV	**19**	**820**	**454**	**6717**	**13**	**1.0**
STDEV	**4**	**104**	**51**	**778**	**0.0**	**0.0**
rel. STDEV [%]	**20**	**13**	**11**	**12**	**0.1**	**4**
Scenario #5						
Simulation #	**background EtOH [ppm]**	**peak EtOH [ppm]**	**extrapol. EtOH [ppm]**	**AUC* [ppm*min]**	**AUC time intervall [min]**	**air exchange rate [h^{-1}]**
1	1.43	85	33	508.2	13	2
2	2.32	74	27	411.2	13	2
3	2.9	95	28	452.2	13	2
MV	**2**	**85**	**29**	**457**	**13**	**2**
STDEV	**1**	**8**	**3**	**40**	**0**	**0**
rel. STDEV [%]	**27**	**10**	**9**	**9**	**0**	**11**
Minimum exposure reduction [%]	**NA**	**85.3**	**91.9**	**90.8**	**NA**	**NA**
Maximum exposure reduction [%]	**NA**	**92.2**	**95.2**	**94.8**	**NA**	**NA**
Mean exposure reduction [%]	**NA**	**89.7**	**93.5**	**93.2**	**NA**	**NA**

* AUC = measure of the total amount of ethanol measured at sampling probe over a time interval of 13 min after opening spigot.

Table 29: Effectiveness of Scenario #6 in comparison to baseline scenario #1 and scenario #5.

Scenario #1						
Simulation #	background EtOH [ppm]	peak EtOH [ppm]	extrapol. EtOH [ppm]	AUC* [ppm*min]	AUC time intervall [min]	air exchange rate [h^{-1}]
1	22	850	454	6963	13	1.04
2	14	873	424	6601	13	0.95
3	15	645	410	5554	13	0.95
4	23	782	430	6502	13	0.95
5	20	953	553	7964	13	1.04
MV	**19**	**820**	**454**	**6717**	**13**	**1.0**
STDEV	**4**	**104**	**51**	**778**	**0.0**	**0.0**
rel. STDEV [%]	**20**	**13**	**11**	**12**	**0.1**	**4**
Scenario #5						
Simulation #	background EtOH [ppm]	peak EtOH [ppm]	extrapol. EtOH [ppm]	AUC* [ppm*min]	AUC time intervall [min]	air exchange rate [h^{-1}]
1	1	85	33	508	13	2
2	2	74	27	411	13	2
3	3	95	28	452	13	2
MV	**2**	**85**	**29**	**457**	**13.0**	**1.8**
STDEV	**1**	**8**	**3**	**40**	**0.0**	**0.2**
rel. STDEV [%]	**27**	**10**	**9**	**9**	**0.0**	**11**
Scenario #6						
Simulation #	background EtOH [ppm]	peak EtOH [ppm]	extrapol. EtOH [ppm]	AUC*# [ppm*min]	AUC time intervall [min]	air exchange rate [h^{-1}]
1	1	5	3	20	8	15
2	1	3	2	19	8	15
3	1	3	2	17	8	15
MV	**1**	**4**	**2**	**19**	**8**	**15**
STDEV	**0**	**1**	**0**	**1**	**0**	**0**
rel. STDEV [%]	**4**	**23**	**16**	**6**	**0**	**3**
Minimum exposure reduction[a] [%]	**NA**	**99.3**	**99.3**	**99.6**	**NA**	**NA**
Maximum exposure reduction[a] [%]	**NA**	**99.7**	**99.7**	**99.8**	**NA**	**NA**
Mean exposure reduction[a] [%]	**NA**	**99.6**	**99.5**	**99.7**	**NA**	**NA**

Minimum exposure reduction[b] [%]	**NA**	**93.5**	**89.6**	**95.1**	**NA**	**NA**
Maximum exposure reduction[b] [%]	**NA**	**96.9**	**94.3**	**96.6**	**NA**	**NA**
Mean exposure reduction[b] [%]	**NA**	**95.7**	**92.1**	**95.9**	**NA**	**NA**

* AUC = measure of the total amount of ethanol measured at sampling probe over a time interval of 13 min after opening spigot.

[a] compared to scenario #1

[b] compared to scenario #5

[#] partly extrapolated AUC

Table 30: **Effectiveness of Scenario #7 in comparison to baseline scenario #1 and scenario #5.**

Simulation #	background EtOH [ppm]	peak EtOH [ppm]	extrapol. EtOH [ppm]	AUC* [ppm*min]	AUC time intervall [min]	air exchange rate [h^{-1}]
Scenario #1						
1	22	850	454	6963	13	1
2	14	873	424	6601	13	1
3	15	645	410	5554	13	1
4	23	782	430	6502	13	1
5	20	953	553	7964	13	1
MV	**19**	**820**	**454**	**6717**	**13**	**1**
STDEV	**4**	**104**	**51**	**778**	**0**	**0**
rel. STDEV [%]	**20**	**13**	**11**	**12**	**0**	**4**
Scenario #5						
Simulation #	**background EtOH [ppm]**	**peak EtOH [ppm]**	**extrapol. EtOH [ppm]**	**AUC* [ppm*min]**	**AUC time intervall [min]**	**air exchange rate [h^{-1}]**
1	1	85	33	508	13	2
2	2	74	27	411	13	2
3	3	95	28	452	13	2
MV	**2**	**85**	**29**	**457**	**13**	**2**
STDEV	**1**	**8**	**3**	**40**	**0**	**0**
rel. STDEV [%]	**27**	**10**	**9**	**9**	**0**	**11**
Scenario #7						
Simulation #	**background EtOH [ppm]**	**peak EtOH [ppm]**	**extrapol. EtOH [ppm]**	**AUC* [ppm*min]**	**AUC time intervall [min]**	**air exchange rate [h^{-1}]**
1	2	13	6	39	8	14
2	3	6	5	27	8	14
3	2	6	5	24	8	15
MV	**3**	**8**	**5**	**30**	**8**	**15**
STDEV	**0**	**3**	**0**	**7**	**0**	**0**
rel. STDEV [%]	**14**	**39**	**8**	**23**	**0**	**3**
Minimum exposure reduction[a] [%]	**NA**	**98.0**	**98.6**	**99.3**	**NA**	**NA**
Maximum exposure reduction[a] [%]	**NA**	**99.4**	**99.1**	**99.7**	**NA**	**NA**
Mean exposure reduction[a] [%]	**NA**	**99.0**	**98.9**	**99.6**	**NA**	**NA**

Minimum exposure reduction[b] [%]	**NA**	**86.4**	**83.0**	**92.3**	**NA**	**NA**
Maximum exposure reduction[b] [%]	**NA**	**91.8**	**82.3**	**94.2**	**NA**	**NA**
Mean exposure reduction[b] [%]	**NA**	**90.1**	**82.7**	**93.5**	**NA**	**NA**

* AUC = measure of the total amount of ethanol measured at sampling probe over a time interval of 13 min after opening spigot.

[a] compared to scenario #1

[b] compared to scenario #5