Study on Recycling of Cooling and Freezing Appliances Containing Vacuum Insulation Panels (VIPs)

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CECED European Committee of Manufacturers of Domestic Equipment

CECED represents the household appliance industry in Europe. Its member companies are mainly based in Europe: CECED member companies produce large household appliances (including refrigerators, freezers, dishwashers, washing machines, and clothes dryers), small household appliances (covering a wide range of products from shavers to vacuum cleaners) and heating, ventilation, and air conditioning equipment, mainly for residential use.

Direct Members of CECED are Arçelik, Ariston Thermo Group, BSH Bosch und Siemens Hausgeräte, Candy Group, Daikin Europe, De'Longhi, Electrolux, Fagor Group, Gorenje, Indesit Company, LG Electronics, Liebherr, Miele, Philips, Samsung Electronics, Groupe SEB, Vorwerk and Whirlpool Europe. CECED member associations cover the following countries: Austria, Belgium, Czech Republic, Denmark, Estonia, France, Germany, Greece, Hungary, Italy, Latvia, Lithuania, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Spain, Sweden, Switzerland, Turkey and the UK.

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List of Abbreviations

%	percent
°C	degree Celsius; unit of temperature
AVAW	Waste Processing Technology and Waste Management; in German “Abfallverwertungstechnik und Abfallwirtschaft”
AWG	Austrian Waste Management Act; in German “Abfallwirtschaftsgesetz”
C&F	cooling and freezing
ca.	circa
CECED	European Committee of Domestic Equipment Manufacturers; in French “Conseil Européen de la construction d'appareils domestiques“
CENELEC	European Committee for Electrotechnical Standardization; in French “Comité Européen de Normalisation Électrotechnique“
CFC	chlorofluorocarbon
cm	centimetre; unit of length
e.g.	for example; in Latin “exempli gratia”
EAG-VO	Austrian WEEE Ordinance; in German “Elektroaltgeräteverordnung”
EERA	European Electronics Recyclers Association
ElektroG	German WEEE Act; in German “Elektrogesetz”
EPA	Swiss Environmental Protection Act
etc.	and so on; in Latin “et cetera”
EU	European Union
EWC	European Waste Catalogue
GWP	global warming potential
HC	hydrocarbon
HCFC	hydro chlorofluorocarbon
HFC	hydro fluorocarbon
i.e.	that is; in Latin “id est”
kg	kilogramme; base unit of mass
KrWG	German Recycling Management Act; in German “Kreislaufwirtschaftsgesetz“
LLDPE	linear low density polyethylene
MG	material group
mm	millimetre; unit of length
MSDS	material safety data sheet
ORDEE	Swiss Ordinance on the Return, the Take Back and the Disposal of Electrical and Electronic Equipment
ORRChem	Swiss Ordinance on Chemical Risk Reduction
PCB	polychlorinated biphenyl
PCT	polychlorinated terphenyl
PET	polyethylene terephthalate
PM	project manager
q.v.	which see; of Latin “quod vide“
QZ	cross flow crusher; in German “Querstromzerspaner”
RoHS	Restriction of Hazardous Substances Directive
t	tonnes; unit of mass
T	temperature;
VFC	volatile fluorocarbon
VHC	volatile hydrogen carbon
VIP	vacuum insulation panel
VOC	volatile organic carbon
WEEE	Waste Electrical and Electronic Equipment
WFD	Waste Framework Directive

I. Executive Summary

The use of Vacuum Insulation Panels (VIPs) in cooling and freezing (C&F) appliances has gradually increased since 2010 due to its better insulation performance compared with PU-foam. VIPs can be found in new C&F appliances of energy class A++ and A+++. Currently low quantities of these types of C&F appliances waste are arriving at recycling plants, however, it is expected that this amount will increase in the coming years.

CECED, the European Committee of Manufacturers of Domestic Equipment, decided to carry out an own-initiative study on the impacts of the VIPs on the recycling process of C&F appliances and transfer the findings of this study to the actors involved in the WEEE management chain, in line with the requirement of providing free of charge information established under the WEEE Directive 2012/19/EU.

The University of Leoben was contracted to analyse the technological aspects of the VIPs and their influence on the recycling process. Small scale tests in laboratories were performed in order to determine the impacts of physical properties of VIPs when shredding in a pilot plant. The results of this first stage were used to prepare three large scale tests in three different recycling plants across Europe. The consultancy team also analysed the feasibility of the current technology practices for the recycling of C&F appliances containing VIPs.

The study started in January 2013 and was finalised in January 2014. The present document summarises how the tests were performed and what conclusions were reached on the impacts on recycling processes.

To perform the study, CECED members provided VIPs directly from their suppliers. In total 15 different VIPs were tested, classified in 6 different material groups according to the visual aspect of the core material (colour and fibres/wool or powder).

Laboratory tests showed that main chemical component of the VIPs' core material is silicon dioxide present in different quantities depending on the type of VIP. Other compounds such as calcium oxide, aluminium oxide, iron (III) oxide, sodium oxide and a sum of organic material are also part of the core material. During some shredding tests in the pilot plants dust generation occurred in four of the six material groups. This aspect was taken into account for the preparation of the large scale tests.

The three large scale tests were performed following the same process scheme. Empty C&F appliances were filled with VIP panels in order to simulate the worst case possible scenario for operating. In each recycling plant, six batches of refrigerators were treated under the same day-by-day operational conditions. Each batch contained refrigerators filled with VIPs of one material group. During the treatment process different process indicators were monitored such as temperature, humidity, differential pressure in filter systems, as well as output streams (PU-Foam, plastics and metals).

Despite the different technologies used in the three plants, general results regarding the recyclability of C&F appliances containing VIPs could be outlined:

- Three of the six material groups caused formation of dust when appliances were treated. In these cases the filter system and the air rate should be checked and adapted if necessary Output materials were not affected and the majority of the VIPs components can be found in the PU-foam output stream.

The main conclusions of the study are:

- Treatment of C&F appliances containing VIPs is feasible with the current technology.
- The impact of VIPs in recycling plants depends on the processing technology of the plant as well as the core material of the VIPs.
- Health and Safety working conditions should be assessed when treating VIPs.
- The amount of C&F appliances containing VIPs will probably increase in the next years; therefore the necessity of adapting technologies should be assessed in an individual basis by recyclers.

In addition, these conclusions are supported by a complementary large scale test carried out by some members of CECED in partnership with the Institut für Energie- und Umwelttechnik (IUTA) in a fourth recycling plant. Only powdery VIPs were tested. The results of this fourth large scale test study are similar to the one undertaken for CECED. Depending on the processing technology, dust emissions are expected when treating C&F appliances containing powdery VIPs. However treating these appliances seems feasible in today's recycling plants.

ACKNOWLEDGMENTS

CECED would like to thank the recycling plants who voluntarily participated in the large scale tests. Their cooperation and the assistance provided by the staff and managers was greatly appreciated.

II. Introduction

CECED, acting as the representative of the household appliance industry in Europe, is releasing the results of this study, with the intention of fulfilling the provisions stated by the DIRECTIVE 2012/19/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 4 July 2012 on waste electrical and electronic equipment (WEEE) regarding the obligations of producers to provide information to waste management actors, free of charge, in respect of each new type of EEE. This is to facilitate the management, and particularly the treatment, recycling and recovery of WEEE (Recital 26 and Art.15).

In this light, the chair of Waste Processing Technology and Waste Management (AVAW) of the Montanuniversitaet Leoben was assigned by CECED to investigate the European status quo on usage of vacuum insulation panels (VIPs) in cooling and freezing household appliances. The project analysis the following aspects:

- Material specific as well as technological aspects
- Realisation of small technical (lab-size) tests and establishing of testing schemes
- Carrying out of large-scale tests and evaluation of project results

This document is a summary of the study and all the relevant findings analysed by AVAW are included.

To support the CECED study with Montanuniversitaet Leoben two CECED members started to collect VIP containing corpora and doors in Germany. Therefore a complementary large scale test was carried out by some members of CECED in partnership with the Institut für Energie- und Umwelttechnik (IUTA) in a fourth recycling plant in Germany. The results of this fourth test are similar to the ones undertaken for CECED and can be found in detail in Appendix 2 of this study.

1. Problem Statement

VIPs or so-called vacuum insulation panels have been used as insulation materials for different purposes, e.g. buildings, houses etc. Recently (since about 2010), producers of cooling and freezing (C&F) household appliances have also started to use VIPs as insulation material in their products. Compared to the commonly used PU-foam, VIPs have better insulation properties. For this reason, the storage volume of C&F appliances can be increased. It is expected that the amount of mentioned “new” appliances will increase. Therefore, it has to be investigated, if conventional treatment and recycling plants are suitable for this “new” waste streams and which technical adjustment and optimisation is needed. Finally, the influence of different materials, used as VIP on output streams (e.g. metals, non-metals etc.) from treatment plants is discussed.

2. Objective

Within this project, the following aims should be achieved:

- effect on a range of available recycling technologies;
- effect on occupational health and safety conditions at the recycling plants;
- calculation of the recyclability rate, taking into account state of the art technologies;
- impacts on economic value of other output fractions caused by contamination with this material;
- secondary raw materials potential depending on the panel type.

3. Anonymisation Scheme

According to the received data from CECED, several different household appliance producers, as well as a number of VIP suppliers and many household appliance recyclers have been considered. Due to investigations via internet, several other household recyclers were found and contacted per email.

The names of the producers, the suppliers and the names of VIPs were anonymised in the present project. Therefore, the names of the companies are abbreviated in the following way:

- VIPS-1, VIPS-2 etc.: VIP suppliers
- HHP-1, HHP-2 etc.: household appliance producers
- TP -1, TP-2 etc.: recycling plants

III. Material Specific and Technological Aspects of VIPs

This chapter deals with the information received from CECED, information found by internet researches and information from companies, which were contacted in writing. The first part of this chapter focuses on vacuum insulation panels, their physical properties, their components and their effect on health. The focus of the second part of this chapter is the recycling technology of cooling and freezing appliances (C&F appliances).

1. Identification of VIPs Used by Household Producers

To quote the received documents by CECED, the estimated effective life time of appliances containing VIPs is about 10 to 15 years on average. Additionally, it is known that mainly appliances of energy class A++ and A+++ contain VIPs. The amount of cooling and freezing appliances containing VIPs sold per year ranges from 1,000 to 213,000 units – this is a really wide range and does not allow any concrete estimation.

The received VIPs from the suppliers for the testing scheme could be classified into the following six different material groups (also see Figure 5). These six material groups represent the basis for all tests described in this chapter.

- Material group 1 (paper like), received from VIPS-4, VIPS-6, VIPS-10, VIPS-14;
- Material group 2 (white fleece), received from VIPS-4;
- Material group 3 (glass wool like), received from VIPS-13;
- Material group 4 (grey powder), received from VIPS-15;
- Material group 5 (brown powder), received from VIPS-7, VIPS-10;
- Material group 6 (black powder), received from VIPS-9.

Figure 1: Different Material Groups of the Vacuum Insulation Panels

a) Specifications of VIPs

Vacuum insulation panels are high performance thermal insulations. They are used in the building technology as well as in refrigerators and freezers. Their high specific thermal resistivity enables new solutions for slim, but still energy efficient insulations.

Although VIPs are not built in singularly in cooling and freezing appliances, but rather always in a combination with PU-foam, the two types of insulations compete with each other. PU-foam is needed to completely foam out the insulation gaps where the VIPs are fitted in.

That is the reason why appliances containing VIPs can be built with a thinner insulation wall than appliances with a PU-foam insulation. An interesting detail is that the position of the VIP has an influence on the energy efficiency of the whole appliance (Table 6). There is also a big difference concerning the density between VIPs and PU-foam:

- VIP: 150-300 kg/m3
- PU foam: 30-35 kg/m3

Table 1: Influence of VIP's Position on Energy Efficiency

Position of VIP	Energy efficiency improvement
door	10%
door + both lateral sides	20%
door + both lateral sides + back site	30%

Structure of VIPs

The structure of VIPs used in refrigerators and freezers differ only marginally from the VIPs used in the building construction industry. The main components of a vacuum insulation panel are:

- Multilayer envelope (prevention of air inlet);
- Highly-porous core material, e.g. fibreglass (stabilisation against atmospheric pressure);
- Getters (collection of gases leaked through the membrane to ensure vacuum).

In Figure 2 the schematic of a building construction VIP is represented.

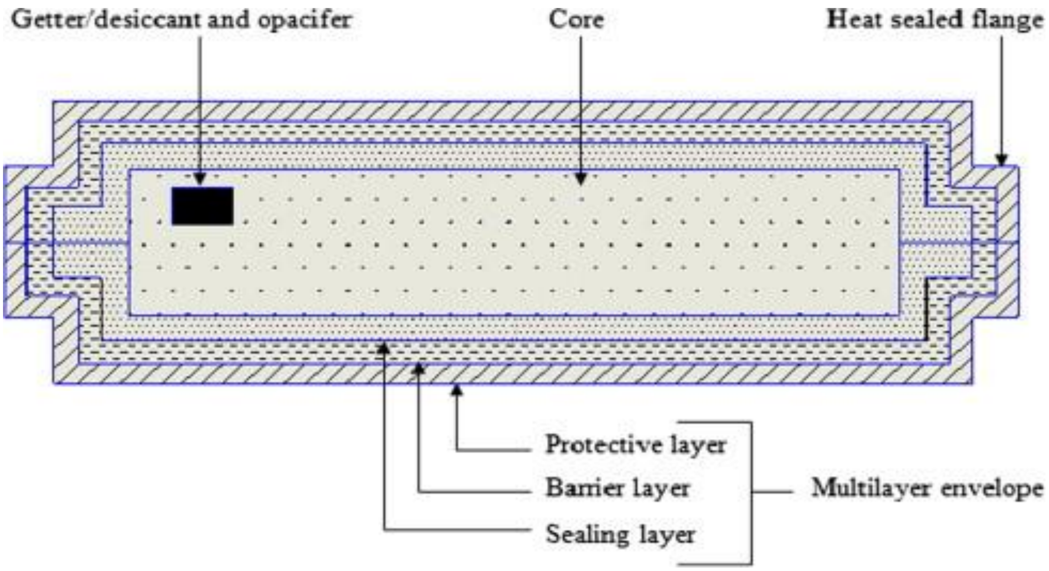

Figure 2: Schematic of a VIP from the Building Construction Industry [Alam]

Based on info-sheets received from CECED, the main components on VIPs of some different VIP suppliers are summarised in Table 2. Every column represents one VIP supplier, with the exception of the third column, which represents two suppliers who have the same descriptions. Concerning the description of the VIP's envelope only three suppliers made specifications, that is why some fields are empty.

Table 2: VIPs' Components of Various VIP Suppliers (anonymised)

Description	VIPS-1	VIPS-4	VIPS-7 / VIPS-9	VIPS-11	VIPS-12
Core material	Chopped fibre glass	Glass board	Silicon dioxide	Amorphous silica (50-100%) Silicon carbide (1-20%)	Micro dispersed silica
Envelope	Multi-layered barrier film	Multi-layered barrier film	-	Polymer filament (1-12%)	-
Getter	Nano getter	Calcium oxide	-	-	-

b) Specifications of VIP Containing Appliances

Vacuum insulation panels are used in C&F appliances since about 2010. According to the documents of CECED, there are several different cooling and freezing appliances with various weight categories and corresponding VIP masses. Some specific examples of these various weight categories are shown in Table 3 and Table 4. In these two tables the third column (percentage of VIPs in appliance) is shown as additional information and not sent by CECED; only the first two columns are quoted from the CECED data. In contrast to Table 4, Table 3 includes a fluctuation rate of the appliance weight and VIP weight.

Table 3: VIPs' Weight Portion in C&F Appliances (data from CECED)

Appliance weight [kg]	VIP weight [kg]	Percentage of VIPs in appliance [%]
100	9	9.0
70	2	2.9
74	4	5.4
78	8	10.3
77	8	10.5
132	4	2.9
77	3	4.4

Table 4: VIPs' Weight Portion in C&F Appliances with Fluctuation Rates (data from CECED)

Appliance weight [kg]	VIP weight [kg]	Percentage of VIPs in appliance [%]
45-105	0.5-2.5	2.0
45-93	0.5-2.5	2.2
140-150	2.5-9	4.0
120-130	2-8	4.0
80-90	3-8	6.5

The information of these two tables is also represented in two bar diagrams: Figure 3 (based on data of) and Figure 4 (based on data of Table 4). In these two following bar diagrams the calculated average weight of the appliances and of the VIPs is shown on the right side.

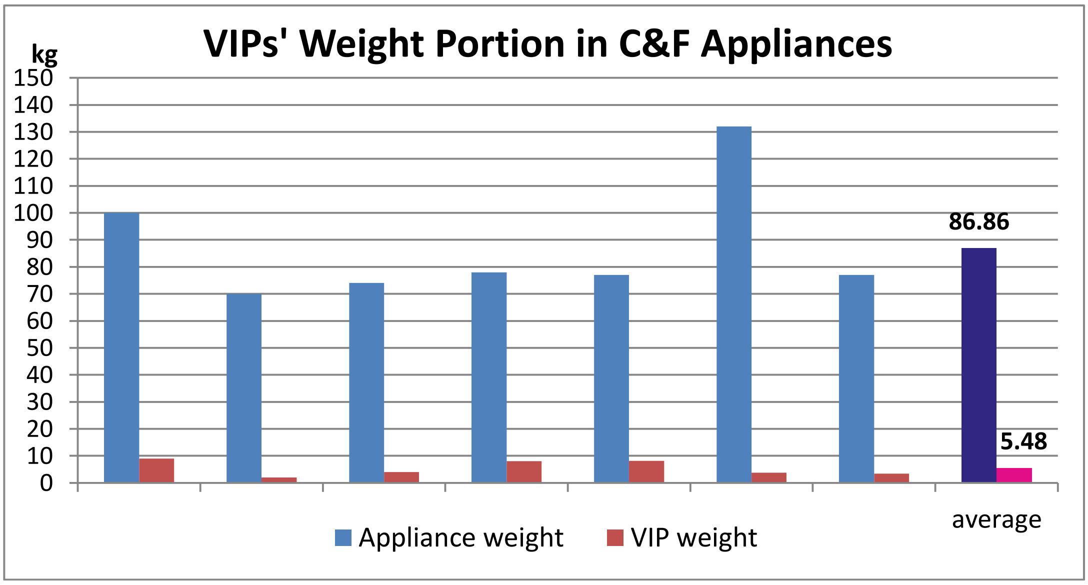

Figure 3: VIPs' Weight Portion in C&F Appliances (based on data from CECED)

The fluctuation rates shown in the following figure are based on the minimum and the maximum weights illustrated in Table 4. Due to the wide range of the weight data, clear allocation is not possible.

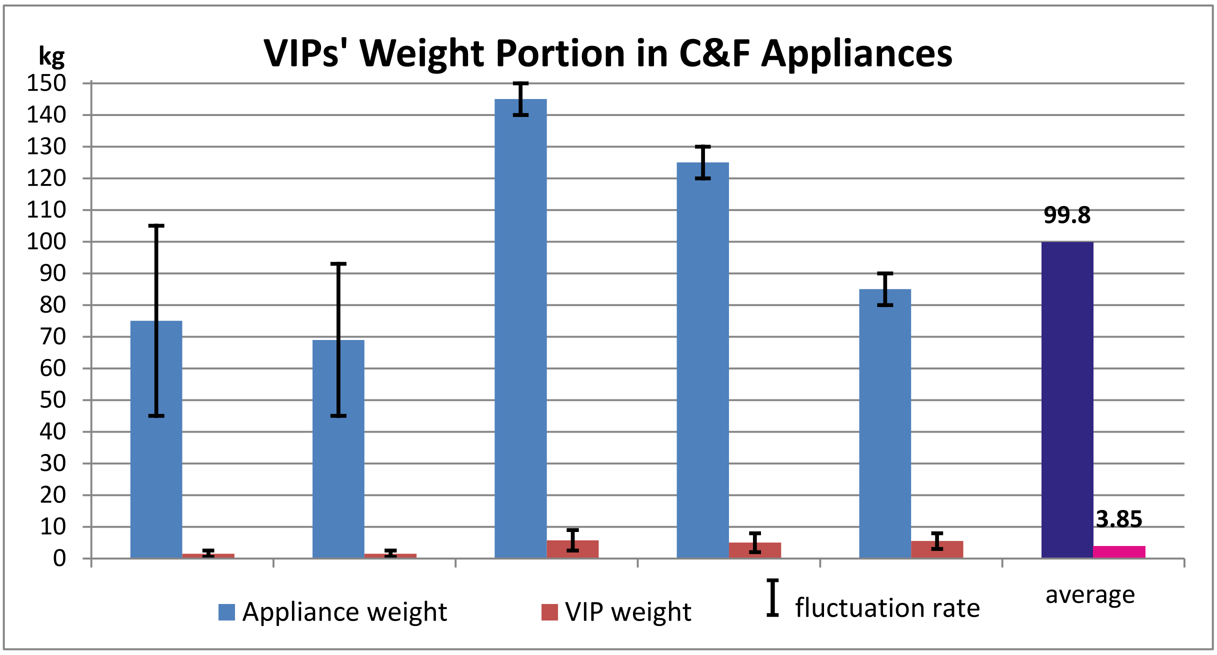

Figure 4: VIPs' Weight Portion in C&F Appliances with Fluctuation Rates (based on data from CECED)

To quote the data by CECED, the average weight of a cooling and freezing appliance containing VIPs is 56 kg with 0.24 to 1.75 kg of VIPs containing. This would mean that the percentage of VIPs in an appliance ranges from 0.43% to 3.13%. But there is a discrepancy between this average percentage and the calculated averages, which are based on the appliance weights and the corresponding VIP weights received by the CECED. These calculated weight averages are shown in Table 5, as well as in Figure 3 and in Figure 4 on the right side.

Table 5: VIPs' Average Portion in C&F Appliances (calculation based on data by CECED)

Appliance weight [kg]	**VIP weight [kg]**	**Percentage of VIPs in appliance [%]**
86.86	5.48	6.3
99.80	3.85	3.9

The difference between the received average weight from CECED and the calculated average çbased on the specific examples of CECED is quite large. Question is, which portion is representative for the European market.

To quote the report from 2011 created by Renato Sarc and Josef Adam at Montanuniversitaet Leoben (q.v. [Sarc]), a C&F appliance of category A++ contains about 5% of VIPs (see Figure 5). This percentage is in line with the received data from CECED.

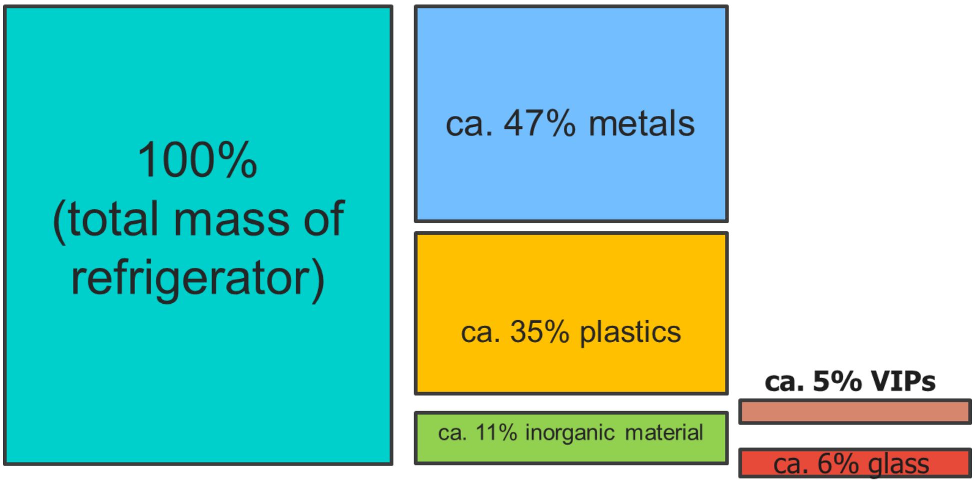

Figure 5: Mass Balance of C&F Appliances Based on an A++ Cooling Appliance [Sarc]

c) Health and Safety Conditions

The impact on health and safety conditions was investigated with the aid of the received material safety data sheets (MSDS) from VIP suppliers and household appliance producers. Table 6 shows the companies, who sent MSDS. Based on the received safety data sheets from the suppliers and the appliance producers, a summarised safety data sheet was created (see Appendix **Error! Reference source not found.**) in accordance with the REACH regulation Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency).

Table 6: Companies who Sent Material Safety Data Sheets

Company (VIP supplier)	**Company** (Household appliance producer)	**Material Group**
VIPS-1	HHP-15	MG3
VIPS-2	HHP-8	MG4
VIPS-7	HHP-12, HHP-3	MG5
VIPS-8	HHP-9	MG1
VIPS-9	HHP-3, HHP-7, HHP-10	MG6
VIPS-11*	-	-
VIPS-12*	-	-

*) VIPS-11 and VIPS-12 sent only MSDSs, but no panels.

According to the information contained in the MSDS received from VIP producers no health and safety risks are expected

2. Small technical test and Testing Scheme

In this chapter the small technical tests as well as an analytical test are described, which were realised on 19th, 20th and 21st March 2013 in Graz and Leoben. These small technical tests were necessary to determine possible health and safety conditions at the recycling plant. They are the basis for planning and organising the large-scale practical tests. For these tests, nine different VIP packages, received from seven different suppliers, were tested. The investigated VIPs were classified into six different material groups as shown in Table 7.

The small technical tests are divided in two types of tests:

- Shredding test (chapter 3);
- Sieving analysis (chapter 4).

The preparation of the material for the analytical part of the tests, an X-ray fluorescence analysis (XRF analysis) as well as the XRF analysis itself were realised in Leoben at the Montanuniversitaet (see chapter 5).

Table 7: Classification of Investigated VIP Material Groups

Abbreviation	Material Group	Description	Supplier	Picture of Material
MG1	material group 1	paper like	VIPS-6, VIPS-10, VIPS-14, VIPS-4	
MG2	material group 2	white fleece	VIPS-4	
MG3	material group 3	glass wool like	VIPS-13	
MG4	material group 4	grey powder	VIPS-15	

MG5	material group 5	brown powder	VIPS-7, VIPS-10	
MG6	material group 6	black powder	VIPS-9	

3. Shredding of VIPs

For shredding the received VIPs, a four-shaft shredder with a 25 mm screen was used. With a band conveyor the shredded material was moved from the four-shaft shredder into buckets, where the shredded material was collected.

Table 8: Used Equipment for Shredding Test

Used Equipment	four-shaft shredder with a 25 mm screen	UNTHA, 12/2005 model, type RS40-4.S, serial number: RS432875480mm
	band conveyor	

All material groups (MG1 to MG6 successively) were shredded easily by the four-shaft shredder.

All materials except MG1 (paper like) and MG3 (glass wool like) caused a heavy formation of dust during the shredding process. This could represent a problem in an operating processing plant for refrigerators.

4. Sieving Analyses of Shredded VIPs

The sieving analyses, which were carried out on 19th and 20th March 2013 in Leoben at the Chair of Waste Processing Technology and Waste Management, focus on an investigation of the shredded material groups MG1, MG2, MG3, MG4 and MG5[1]. The target was to determine, whether a separation of aluminium from the core material by sieving could be possible. Two types of sieving analysis were realised (one dry and one humidified), because refrigerators might be humid in refrigerator recycling plants:

- Sieving analyses with dry shredded material
- Sieving analyses with humidified shredded material (15 mass% water)

[1] Due to the characteristics of MG6, being very powdery and dusty, MG6 was excluded from the sieving analysis.

Due to these two types, it was also a target to determine, if there is a difference between the dry and the humidified material, because the same material was sieved twice. Based on the mesh opening of the shredder's screen of 25 mm, the following sieve openings were used for both sieving analyses (in total 7 levels): 20 mm, 16 mm, 10 mm, 6.3 mm, 4 mm, 2 mm and a sieve bottom. In Figure 6, the used sieve tower with six sieves and the bottom are represented on a mechanical shaker. As shown in Table 9, the total masses of the sieved materials vary. This variation results from the difference of the materials' densities, because the goal for the sieving analyses was to work with similar volumes, not masses.

Figure 6: Sieve Tower on Mechanical Shaker

Table 9: Sieving Analyses of Dry Materials

Dry material	Total mass [g]	> 20 mm [g]	> 16 mm [g]	> 10 mm [g]	> 6.3 mm [g]	> 4 mm [g]	> 2 mm [g]	< 2 mm [g]
MG1	**346.9**	53.5	38.7	63.2	35.1	14.8	7.4	134.2
MG2	**775.3**	35.1	85.4	126.4	92.8	64.6	90.0	281.0
MG3	**281.2**	9.6	6.1	77.6	103.6	37.9	6.2	40.2
MG4	**363.5**	37.3	25.6	62.4	99.8	45.2	21.0	72.2
MG5	**434.6**	13.9	31.3	157.7	101.0	18.3	12.4	100.0

Based on the total mass of the first sieving analysis, the water content of approximately 15 mass% was calculated, because the same material was sieved twice. The results of the sieving analyses of the humidified material are shown in Table 10.

Table 10: Sieving Analyses of Humidified Materials

Humidified material	Total mass [g]	Added water [g]	> 20 mm [g]	> 16 mm [g]	> 10 mm [g]	>6.3 mm [g]	> 4 mm [g]	> 2 mm [g]	< 2 mm [g]
MG1	**399.8**	66.1	214.5	1.7	63.7	48.2	17.2	7.5	47.0
MG2	**901.3**	140.2	56.1	65.6	178.2	134.0	76.1	111.0	280.3
MG3	**316.8**	50.1	77.8	22.8	111.8	68.9	25.6	3.0	6.9
MG4	**422.2**	65.1	47.2	35.2	55.1	87.1	65.9	24.8	106.9
MG5	**498.0**	80.3	60.1	48.4	118.7	84.9	13.8	6.3	165.8

In chapter 6 every sieve of the resulted particle size distribution is shown.

5. XRF Analysis of VIPs' Core Materials

Because the core materials of MG5 and MG6 have been already analysed by an X-ray fluorescence analysis within the report written by Renato Sarc and Josef Adam in 2011 [Sarc], only the core materials of MG1, MG2, MG3 and MG4 were analysed. Before analysing, they had to be grinded by a ball mill to ensure that the material is homogenous and powdery. The results of the XRF analyses are shown in chapter 6.

6. Results and Interpretation of the Testing Scheme

This chapter contains the results of the previous described tests. On the following pages the particle size distribution of every single material group (MG1 to MG6) are summarised as well as the chemical elements contained in VIPs.

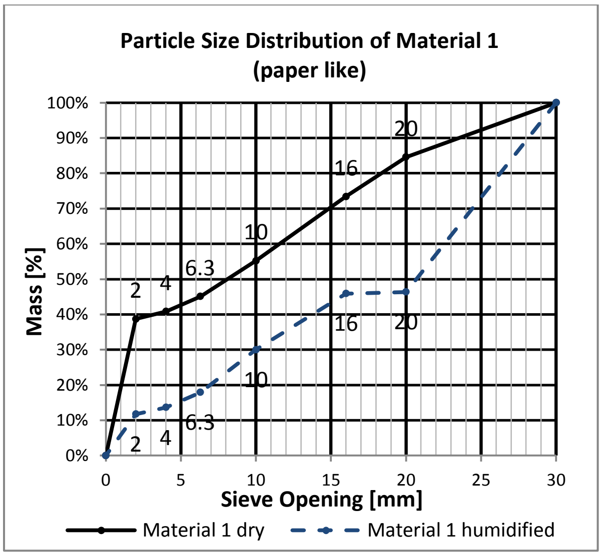

Figure 7: Particle Size Distribution of MG1

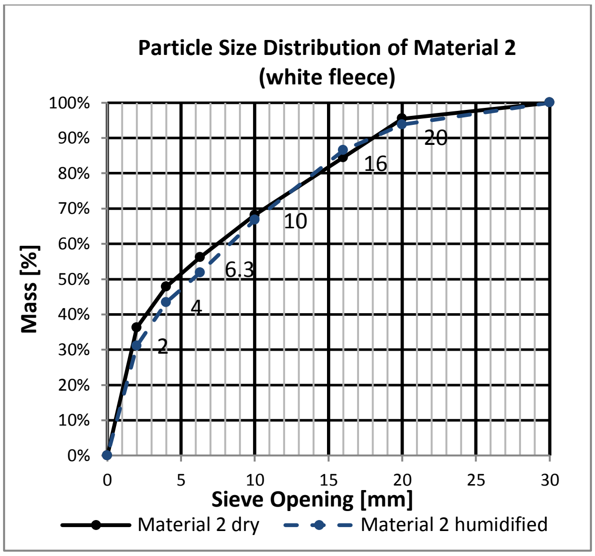

Figure 8: Particle Size Distribution of MG2

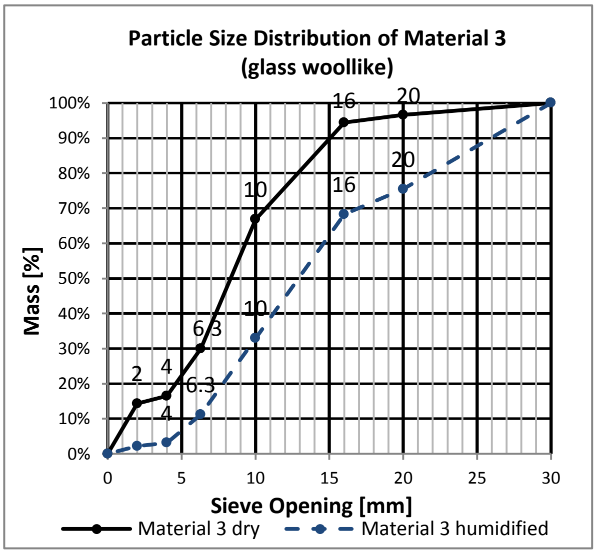

Figure 9: Particle Size Distribution of MG3

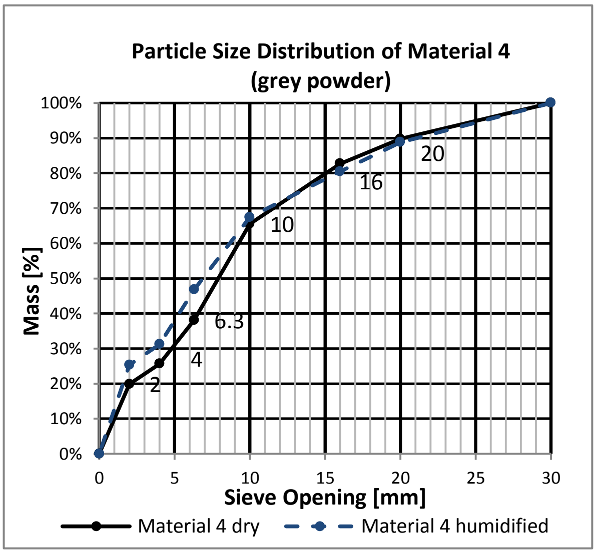

Figure 10: Particle Size Distribution of MG4

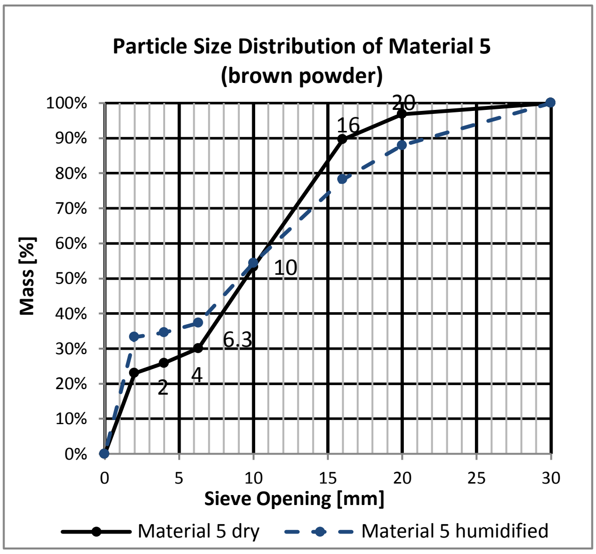

Figure 11: Particle Size Distribution of MG5

a) Summary of the Chemical Elements in VIPs

In Table 11 the main components of the analysed materials are listed. It is obvious that silicon dioxide is the most used material as core material for VIPs.

Table 11: Summary of the Chemical Main Components of the Material Groups

Compound/ Chemical Formula		Weight [%]					
		MG1 paper like	MG2 white fleece	MG3 glass wool like	MG4 grey powder	MG5 brown powder	MG6 black powder
Silicon dioxide	**SiO_2**	69.08	54.08	51.03	98.01	88.00	71.12
Calcium oxide	**CaO**	8.81	24.97	30.13	-	-	-
Aluminium oxide	**Al_2O_3**	-	13.57	14.10	-	-	-
Iron(III) oxide	**Fe_2O_3**	-		-	-	-	22.41
Sodium oxide	**Na_2O**	14.09	-	-	-	-	-
Sum of organic material		0.27	2.76	1.22	1.19	5.98	3.15

Regarding the main components of the VIPs' core materials, they are basically adapted for a recycling in cement industry (q.v. [Sarc]). It can be assumed, that the other core materials would also fulfil criteria for a recycling in the cement industry. Other possibilities for a recycling of the VIPs' core materials would be given in the glass industry as well as in the ceramics industry.

IV. Large Scale Tests

Within the framework of the large-scale tests, the previously mentioned six material groups and their impacts on recycling plants, when being treated together with cooling and freezing appliances, should be investigated. This chapter deals with the preparation and the results of the large-scale tests. The first part describes the planning phase as well as the approach to the several plants, which were in line for the large-scale test. The second part deals with the results of the performed tests in the chosen plants.

1. Planning Phase of Large-scale Test

Initially, contemplable recycling plants of C&F appliances in Europe had to be chosen. Ten different European recycling plants came into question for the large-scale test. The task was to select three plants out of these ten possible plants (they are shown in Table 12, as well as a short description of their technology. The decision was based on the following criteria:

1. Willingness of the plant operator;
2. Every state of the art technology in Europe should be represented;
3. Nitrogen atmosphere in shredding unit;
4. Monitoring available.

TP 7 and TP8 did not meet criterion 1. TP9 did not meet criterion 2, because they do not use a nitrogen atmosphere. TP6 only wanted to perform a small test (i.e. less than five appliances), because they have doubts concerning the dust emissions and equipment disturbances, which were confirmed in the past months. In the TP2 the same processing technology (SEG technology) is used as in the TP1. Because of easier logistics from Leoben to TP1, this plant was preferred. By comparing the TP10 and TP11 with logistical aspects, the TP10 is to prefer. To meet criterion 2, TP3 was chosen over the TP4.

The selection of the plants for the large-scale test finally led to the following three plants..

- TP1;
- TP3;
- TP10.

In July 2013 the TP5 also showed interest to join the large-scale test. The problem is, that this plant has no permission to treat glass wool-containing appliances. A realisation of the large-scale test would be only possible, if the plant gets the permission by authority. That is why it will be kept in reserve, but no fix date is determined.

Table 12: Contemplable Plants for the Large-scale Test

Treatment Plant	Technology
TP1	SEG technology: 4-shaft shredder, active carbon and paper filter, desorption and liquefaction of CFC
TP2	SEG technology:

	4-shaft shredder, active carbon filter, desorption and liquefaction of CFC
TP3	Cross flow crusher (QZ), cryogenic technology
TP4	Two 2-shaft shredders, two hammer mills, mono-rotor-crusher; activated carbon
TP5	4-shaft shredder and cross flow crusher (QZ)
TP6	Cross flow crusher (QZ), active carbon filter and cryogenic technology
TP7	Cross flow crusher (QZ), cryogenic technology
TP8	2-shaft and 4-shaft shredders, granulator, pelletizer and cryogenic technology
TP9	2-shaft and 4-shaft shredder, CFC directly burned (950°C)
TP10	2-shaft and 4-shaft shredder, bag house filter, pelletizer for PU foam, cryogenic technology
TP11	Two cutting units, active carbon units, direct treatment of gases

Time Table for large-scale test

The first test was performed in TP1 (October 2013), the second test was performed in TP10 (October 2013) and the third test was performed in TP3 (October 2013).

a) Calculations for the needed amount of VIPs

For the selected plants the necessary amounts of VIPs were calculated based on the following points:

- Throughput of plants (according to each plant operator);
- Average weight of C&F appliances (according to each plant operator);
- 5 mass% VIPs in C&F appliances;
- 5 hours working time for the test;
- Equal amount of every material group.

Calculations for TP1

The throughput of the TP1 is about 25 to 30 appliances per hour and the average weight of one appliance is 42 kg according to the information from the factory manager of the selected plant .Referring to the points shown above, which represent the basis for the calculation, 60 kg of every VIP type is necessary for the large-scale test in the TP1 (also see Table 13).

Table 13: Calculations of required VIPs for TP1

Calculation	Comment/Explanation
25 – 30 appliances/h · 42 kg = 1050 – 1260 kg/h	max. throughput: 1,260 kg/h
1260 kg/h · 0.05 = 63 kg/h	5 mass% VIPs in C&F appliances (=

	0.05)
63 kg/h · 5 h = 315 kg VIPs in total	5 hours for the test
315 kg / 6 = 52.5 kg ≈ **60 kg of each material group**	6 different material groups
60 kg · 6 = **360 kg VIPs in total**	…should be delivered to TP1

Calculations for TP10

According to the information of the factory manager, the throughput is about 55 to 60 appliances per hour and the average weight for one appliance is 42 kg . Based on this information, the necessary amount of VIPs for the TP10 is 110 kg of each material group of VIPs. The calculations who lead to this result are shown in Table 14.

Table 14: Calculations of required VIPs for TP10

Calculation	Comment/Explanation
55 – 60 appliances/h · 42 kg = 2,300 – 2,500 kg/h	max. throughput: 2,500 kg/h
2,500 kg/h · 0.05 = 125 kg/h	5 mass% VIPs in C&F appliances (= 0.05)
125 kg/h · 5 h = 625 kg VIPs in total	5 hours for the test
625 kg / 6 = 104.2 kg ≈ **110 kg of each material group**	6 different material groups
110 kg · 6 = **660 kg VIPs in total**	…should be delivered to TP10

Calculations for TP3

In this plant approx. 50 appliances with an average weight of 45 kg are treated per hour, according to the factory manager. Referring to this information a necessary amount of 94 kg of each material group of VIPs was calculated as shown in Table 15.

Table 15: Calculations of required VIPs for TP3

Calculation	Comment/Explanation
50 appliances/h · 45 kg = 2,250 kg/h	max. throughput: 2,250 kg/h
2,250 kg/h · 0.05 = 112.5 kg/h	5 mass% VIPs in C&F appliances (= 0.05)
112.5 kg/h · 5 h = 562.5 kg VIPs in total	5 hours for the test
562.5 kg / 6 = 93.75 kg ≈ **94 kg of each material group**	6 different material groups
100 kg · 6 = **600 kg VIPs in total**	…should be delivered to TP3

b) Delivery of VIPs from VIP suppliers

For the large-scale test the previously described six different material groups of VIPs are necessary in an equal amount. It was purposely refrained from reflecting the present market situation of the used VIP types to ensure comparability between all material types. Furthermore, the present market situation is not exactly known and if it was, it could change quickly. In Table 16 the required amounts of VIPs of each supplier are summarised.

Table 16: Required VIP Amounts for the Large-scale Test of each VIP Supplier – First Calculation

Company (Household appliance producer)	**Company** (VIP supplier)	**Material Group**	**Required VIP amount for test in**			**Total required VIP amount**
			TP1	**TP10**	**TP3**	
HHP-18	VIPS-6	MG1	30 kg	55 kg	50 kg	**135 kg**
HHP-9	VIPS-8		30 kg	55 kg	50 kg	**135 kg**
HHP-11	VIPS-4	MG2	60 kg	110 kg	100 kg	**270 kg**
HHP-15	VIPS-1	MG3	60 kg	110 kg	100 kg	**270 kg**
HHP-8	VIPS-2	MG4	60 kg	110 kg	100 kg	**270 kg**
HHP-12	VIPS-7	MG5	30 kg	ca. 55 kg	ca. 50 kg	**135 kg**
HHP-3	VIPS-7		30 kg	55 kg	50 kg	**135 kg**
HHP-10	VIPS-9	MG6	20 kg	ca.36.7 kg	ca. 33.3 kg	**90 kg**
HHP-7	VIPS-9		20 kg	ca.36.7 kg	ca. 33.3 kg	**90 kg**
HHP-3	VIPS-9		20 kg	ca.36.7 kg	ca. 33.3 kg	**90 kg**
Total:			360 kg	660 kg	600 kg	1,620 kg

In summer 2013, some changes on the suppliers' part occurred. That was why the required amounts of VIPs in the previous table had to be recalculated. In Table 17 the new required amounts are summarised. Having no possibility to get MG2, this material group had been removed from the large-scale test. However, during the performance of the large-scale tests some little amounts of MG2-panels were received as well. Therefore, also results for MG2 according it's large-scale suitability for recycling plants could be gained.

Table 17: Required VIP Amounts for the Large-scale Test of each VIP Supplier – Final Version

Company (Household appliance producer)	**Company** (VIP supplier)	**Material Group**	**Required VIP amount for test in**			**Total required VIP amount**
			TP1	**TP10**	**TP3**	
HHP-18	VIPH-6	MG1	30 kg	55 kg	50 kg	**135 kg**
HHP-9	VIPH-8		30 kg	55 kg	50 kg	**135 kg**
HHP-15	VIPH-1	MG3	60 kg	110 kg	100 kg	**270 kg**
HHP-8	VIPH-2	MG4	60 kg	110 kg	100 kg	**270 kg**

HHP-12	VIPH-7	MG5	30 kg	55 kg	50 kg	**135 kg**
HHP-3	VIPH-7		30 kg	55 kg	50 kg	**135 kg**
HHP-10	VIPH-9	MG6	20 kg	ca.36.7 kg	ca. 33.3 kg	**90 kg**
HHP-7	VIPH-9		20 kg	ca.36.7 kg	ca. 33.3 kg	**90 kg**
HHP-3	VIPH-9		20 kg	ca.36.7 kg	ca. 33.3 kg	**90 kg**
Total:			300 kg	550 kg	500 kg	1,350 kg

2. Realisation of Large Scale Test TP1

The first large-scale test was performed in TTP1 on 2nd October 2013. The panels of each of the six material groups MG1, MG2[2], MG3, MG4, MG5 and MG6 were supposed to be treated together with old refrigerators in ascending order. Afterwards, the output materials were examined.

Due to the high humidity in the recycling plant (> 70%), the question raised, what was the effect of moisture on the different core materials of the six material groups and how would the filter systems deal with the expected high amounts of dust.
Basic information on the test are summarised in Table 18.

Table 18: Basic Information on the Large-scale Test in TP1

Date	2nd October 2013
Duration	ca. 4 hours (9:00 – 12:45)
Year of construction	2003; since then regular corrections and adaptions
Technology	SEG technology: 4-shaft shredder, active carbon and paper filter, new special filter, desorption and liquefaction of CFC
Throughput	25 – 30 appliances per hour

After sorting and the division of the received packages into six material groups, the large-scale test was performed. The runs of each material group are explained in the following subchapters.

a) Material Group 1 – Paper Like

24 panels of MG1, to be seen in Figure 12, were distributed among eight refrigerators (three in each appliance).

[2] There were only a few panels of MG2 present.

Figure 12: Panels of MG1 (TP1)

Neither changes in the output fraction "metal" (see Figure 13) nor changes in the output fraction "plastics" (see Figure 14) could be determined during the run of this material group. It can be assumed that all VIPs' components (aluminium foil as well as core material) got in the PU fraction. The treatment of MG1 did not cause any technical problems in the plant.

Figure 13: Output of Metals

Figure 14: Output of Plastics

The basic information of the run with the VIPs of material group 1 is summarised in Table 19.

Table 19: Basic Information on MG1's Test in TP1

Number of appliances	8 appliances
Number of panels	24 panels
Duration	ca. 20 minutes (10:05 – 10:25)
Result	no technical problem for the plant; all VIPs' components (aluminium foil as well as core material) in PU output;

b) Material Group 2 – White Fleece

Due to the little amount of MG2 panels, only nine small panels (see Figure 15), distributed among three appliances (three panels in each appliance), could be tested. The treatment of this material group was equally unproblematic for the plant as MG1. Also the components of

MG2 were found in the PU fraction, while the fractions of metal and plastics did not contain any VIP material.

Figure 15: Panels of MG2 (TP1)

REMARK: During the small scale shredding test, which was performed in an open 2-shaft shredder, this material group caused a heavy formation of dust. Due to the little amount of panels in the large-scale test, this impact could not be determined.

Table 20: Basic Information on MG2's Test in TP1

Number of appliances	3 appliances
Number of panels	9 small panels
Duration	ca. 10 minutes (10:25 – 10:35)
Result	no technical problem for the plant; all VIPs' components (aluminium foil as well as core material) in PU output;

c) Material Group 3 – Glass Wool Like

24 MG3 panels of different sizes (see Figure 16) were distributed among eight appliances, so that each appliance was filled with three panels.

Figure 16: Panels of MG3 (TP1)

While shredding this material, an increase of its volume could be determined by a camera, installed inside the shredder. This also happened during the small-scale shredding test. However, the effect was not as big as expected, which can be explained by the vacuum in the entire system. All VIPs' components of MG3 were found like the components of the other material groups in the PU output. At this point some problems in the unit occurred, where the already shredded PU foam is transported by a screw (the so called discharge screw). There was a blockage, caused by the glass wool fibres. The material tended to form bridges inside the discharge screw. This was the reason why the screw was blocked. The unit had to be opened and cleaned manually, which is obvious in Figure 17.

Figure 17: Opening and Cleaning of the Blocked Screw Discharge (3 Pictures)

The output fraction "PU-foam" also contained aluminium foils and core materials of MG3, which can be seen in Figure 18. A summary of the test with MG3 in TP1 is given in Table 21.

Figure 18: PU Output Mixed Up with VIPs' Material

Table 21: Basic Information on MG3's Test in TP1

Number of appliances	8 appliances
Number of panels	24 panels (various sizes)
Duration	ca. 50 minutes (10:40 – 11:30), including cleaning of blocked unit;
Result	problems with screw discharge → short stop of the operation to clean the unit manually; all VIPs' components (aluminium foil as well as core material) in PU output;

d) Material Group 4 – Grey Powder

27 panels of MG4 (see Figure 19) with different sizes were distributed among nine refrigerators, to fill every appliance with three panels.

Figure 19: Panels of MG4 (TP1)

The core material of MG4 is very powdery and fine-grained, what caused a heavy formation of dust inside the plant. Due to the dust, it was soon impossible to see anything on the camera, installed inside the shredder. With every input of an appliance into the shredder, dust streamed into the preparing hall. After about 20 minutes, the dust inside the hall caused a smoke alarm.

The installed paper filter was equipped with a new filter paper just one week before the test. Furthermore, the filter system was complemented by a new cyclone filter unit. Despite this new filter, dust (in combination with air humidity) was bounded on the filter surface as well as on the inner surface of the feed hose. Due to the heavy deposits on the paper filter (according to the facility manager “these amounts of dust do not even occur after one month of normal operation”), a conventional cleaning by counter pressure was not possible. The filter had to be cleaned manually. The deposits in the feed hoses had a greasy characteristic, because of the high humidity. The other units of the exhaust air system had to be cleaned too. In
Table 22 the basic information on the test with MG4 is summarised.

Figure 20: Deposits on paper filter

Figure 21: Deposits in feed hose

Table 22: Basic Information on MG4's Test in TP1TP1

Number of appliances	9 appliances
Number of panels	27 panels (various sizes)
Duration	ca. 35 minutes (11:40 – 12:15), except cleaning exhaust air system;
Result	heavy formation of dust → stop of the plant; cleaning of exhaust air system necessary; all VIPs' components (aluminium foil as well as core material) in PU output;

e) Stop of the Test

To avoid possible damages of the plant, the panels of MG5 (see Figure 22) and of MG6 (see Figure 23) were not tested.

Figure 22: Panels of MG5 (TP1)

Figure 23: Panels of MG6 (TP1)

The core materials of these two material groups were comparable (physical and chemical characteristics) to MG4's core material. That is why it was assumed that also MG5 and MG6 would cause heavy technical problems for the plant in TP1 and so the test was stopped.

f) Summary of the Test in TP1

The test in TP1 made clear, that, when being treated in a recycling plant, the material groups MG1, MG2 and MG3 react differently to the powdery material groups MG4, MG5 and MG6. Due to the heavy deposits in the filters and the exhaust air systems, the test was aborted after the MG4 run. A summary of all important facts of the performed tests in TP1 is given in Table 23.

Table 23: Summary of the Large-scale Test in TP1

Number of appliances in total	28 appliances
Number of panels in total	84 panels (various sizes, 4 different material groups)
Duration	ca. 4 hours (9:00 – 12:45)
Result	MG1, MG2 and MG3: no technical problem for recycling plant; MG4 (first powdery material): heavy formation of dust → stop of the plant; cleaning of exhaust air system necessary; all VIPs' components (aluminium foil as well as core material) in PU output (used as oil binder);

3. Realisation of the Large-scale Test in TP3

The second large-scale test was performed in the recycling plant TP3 on 14th October 2013.

Similar to the first large-scale test in TP1, the received panels were supposed to be treated in the recycling plant together with refrigerators in ascending order. Because the cross flow crusher (QZ) can be filled at once with five to seven appliances, it was decided to prepare six or seven appliances for each of the six material groups. By filling the QZ exclusively with VIP-containing appliances, a worst case scenario should be guaranteed. The dwelling time of the appliances in the QZ is about 15 minutes. Before each run with the six different material groups, the QZ was emptied, to make sure, that the worst case scenario is reached.

The basic information on the large-scale test in TP3 as well as the attendees are summarised in Table 24.

Table 24: Basic Information on the Large-scale Test in TP3

Date	14th October 2013
Duration	ca. 6 hours (9:00 – 17:00; excluding lunch break)
Year of construction	2008
Technology	MeWa technology: cross flow crusher (QZ), bag house filter systems, cryo technology
Throughput	50 appliances per hour

Due to heavy problems during the first test in TP1, which occurred with MG4, it was focussed on the filter systems during this test. Especially, the measurement of the differential pressure of the filter, which is installed directly behind the QZ was currently checked (in the following called filter 1). This filter 1 is a bag house filter with an automatic counter pressure cleaning, which is activated about every 20 seconds. A schematic diagram of filter 1 is given in Figure 24. The measured values of filter 1 were read during the entire test (irregular intervals). Chapter g) will deal with the measure values of the filter in detail. In the following subchapters each run of the six material groups are described.

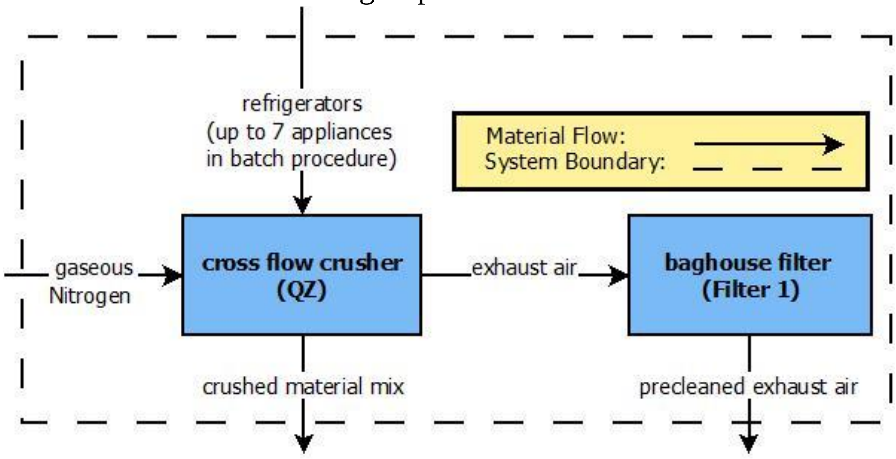

Figure 24: Schematic Diagram of the Bag House Filter (Filter 1) Directly Behind the QZ

a) Material Group 1 – Paper Like

Five appliances with each four panels and one appliance with five panels of MG1 (see Figure 25) were treated by the QZ. No technical problems in the plant were detected. The values of filter 1 were in a normal range (see chapter g)). All VIPs' components went in the PU output. The basic information on the run with MG1 is summarised in Table 25.

Figure 25: Panels of MG1 (TP3)

Table 25: Basic Information on MG1's Test in TP3

Number of appliances	6 appliances
Number of panels	25 panels
Duration	ca. 30 minutes (11:35 – 11:05)
Result	no technical problem for the plant; all VIPs' components (aluminium foil as well as core material) in PU output;

b) Material Group 2 – White Fleece

In total 23 panels of MG2 (see Figure 26) were distributed among seven appliances and put in the plant. The values of filter 1 (see chapter g)) were in normal range and there were no problems in the entire plant. The components of the panels went to the PU output, like MG1. In Table 26, the basic information on the run of MG2 in the TP3 plant is summarised.

Figure 26: Panels of MG2 (TP3)

Table 26: Basic Information on MG2's Test in TP3

Number of appliances	6 appliances
Number of panels	25 panels
Duration	ca. 30 minutes (11:35 – 11:05)
Result	no technical problem for the plant; all VIPs' components (aluminium foil as well as core material) in PU output;

c) Material Group 3 – Glass Wool Like

Six appliances filled with 30 small MG3 panels in total (see Figure 27) were treated in the plant. Although the value of filter 1 were in a normal range (see chapter g)), the set point of the oxygen content inside the QZ was exceeded. The maximum value is 4.5%, but the measured value at 12:10 was 5.3%. However, this did not cause any problems for the plant and the operation could be normally continued. Table 27 contains a summary of the basic information on the test of MG3 in TP3.

Figure 27: Panels of MG3 (TP3)

Table 27: Basic Information on MG3's Test in TP3

Number of appliances	6 appliances
Number of panels	30 small panels
Duration	ca. 20 minutes (12:10 – 12:30)
Result	O_2-value in QZ: 5.3% (max.: 4.5%); apart from that: no technical problem for the plant; all VIPs' components (aluminium foil as well as core material) in PU output;

d) Material Group 4 – Grey Powder

Six appliances with each two big and four small panels of MG4 (see Figure 28) were put in the plant. Out of the fact that this material group represents the first of the three powdery VIPs, the measured values of the differential pressure of filter 1 were read rather often (see chapter g)). The differential pressure Δp of filter 1 was increasing during the shredding process of MG4, but the plant could deal with this increase without any problems. The components of the panels were not found in the fractions plastics and metals, because they went to the PU output. Some basic information on the test with MG4 is given in Table 28.

Figure 28: Panels of MG4 (TP3)

Table 28: Basic Information on MG4's Test in TP3

Number of appliances	6 appliances
Number of panels	36 panels (12 big, 24 small)
Duration	ca. 20 minutes (12:40 – 13:00)
Result	no technical problem for the plant; all VIPs' components (aluminium foil as well as core material) in PU output;

e) Material Group 5 – Brown Powder

In total, 30 MG5 panels of different sizes (see Figure 29) were distributed among six appliances, which were treated all together in the QZ. Except for the lightly increased values of filter 1 (see chapter g)), no technical problems were determined in the plant. All components of the MG5 panels went to the PU output. Table 29 gives an overview of the MG5's run in the TP3 plant.

Figure 29: Panels of MG5 (TP3)

Table 29: Basic Information on MG5's Test in TP3

Number of appliances	6 appliances
Number of panels	30 panels (various sizes)
Duration	ca. 25 minutes (15:25 – 15:50)
Result	no technical problem for the plant; all VIPs' components (aluminium foil as well as core material) in PU output;

f) Material Group 6 – Black Powder

Seven appliances were filled with 40 panels in total of the remaining material group MG6. These panels were rather thin and small, compared to the panels of the other material groups (see Figure 30).

Figure 30: Panels of MG6 (TP3)

During the shredding process of the MG6 panels, the measured values of the differential pressure remained on the same level as for MG5 (see chapter g)). Apart from that, no technical problems occurred in the plant. The basic information on the test with the panels of MG6 is summarised in Table 30.

Table 30: Basic Information on MG6's Test in TP3

Number of appliances	7 appliances
Number of panels	40 small, thin panels
Duration	ca. 30 minutes (16:00 – 16:30)
Result	no technical problem for the plant; all VIPs' components (aluminium foil as well as core material) in PU output;

g) Summary of the Test in TP3

The large-scale test in TP3 plant made clear, that plants of this type are ready to treat VIP-containing appliances without any problems. The worry, that the filter systems would not deal with the dust amounts of MG4, MG5 and MG6 was proved false.

In Figure 31 it is obvious, that the differential pressure Δp, measured at filter 1, is clearly higher during the shredding processes of MG4, MG5 and MG6 than in normal operation. However, this did not cause any problems for the operation in the plant. It is important to know, that the chains inside the cross flow crusher had been changed just before the test started. The plant had to be opened, which caused atmospheric pressure in the plant during the exchange of the chains. After this maintenance of the QZ, nitrogen was injected in the plant again and vacuum had to be built up again. In the course of the day, Δp of filter 1 was increasing, which also can be confirmed by the two "normal" measurments (first at 10:35, second at 15:00).

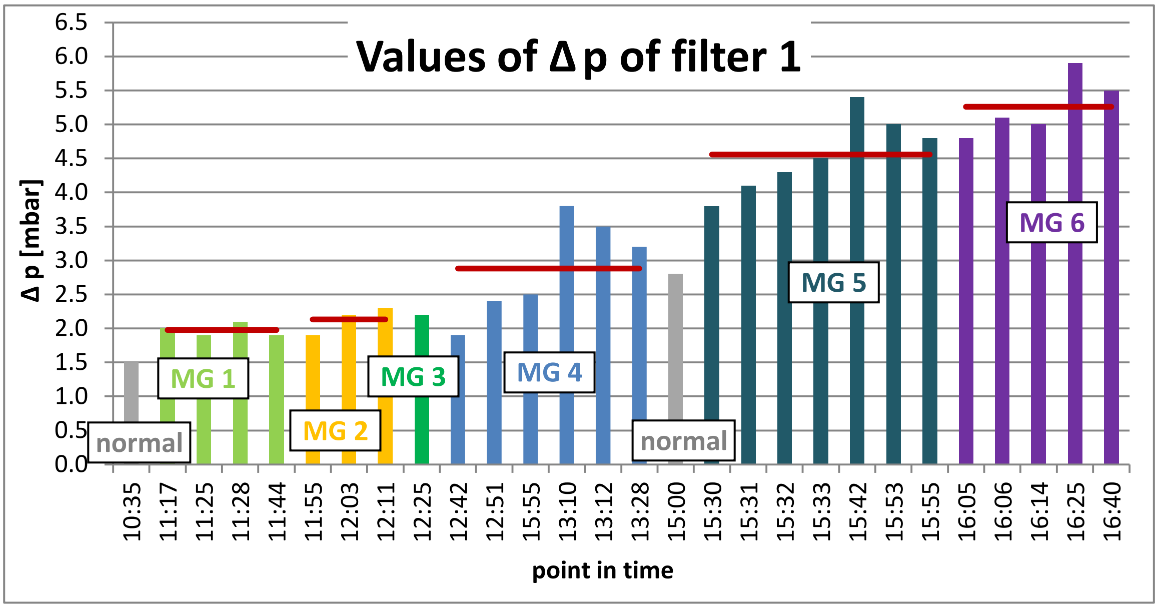

Figure 31: Measurement of Differential Pressure of Filter 1 during the Large-scale Test in TP3 (Red Lines: Average Values)

The components of all VIP types could neither be found in the non-ferrous fraction (see Figure 32) nor in the ferrous fraction. Hence, it can be assumed, that all components of the vacuum insulation panels went to the PU output, which also makes sense regarding the density of the materials. For the TP3, this does not mean a loss of quality of the PU output, because it goes to the cement industry, where silicon dioxide does not disturb, but is even required. Table 31 gives an overview of the performed large-scale test in TP3 and its results.

Figure 32: Non-ferrous Output (TP3)

Table 31: Summary of the Large-scale Test in TP3

Number of appliances in total	38 appliances
Number of panels in total	184 panels (various sizes, 6 different material groups)
Duration	ca. 6 hours (9:00 – 17:00, excluding lunch break)
Result	no technical problem for the plant; increase of Δp at filter 1 during shredding the powdery material groups MG4, MG5, MG6; all VIPs' components (aluminium foil as well as core material) in PU output → no loss of quality, because PU output is used in cement industry;

4. Realisation of the Large-scale Test in TP10

The third and last large-scale test was performed in TP10 on 23th October 2013. The basic information on this large-scale test as well as the attendees are summarised in Table 32.

Due to the high humidity in the location of TP10 (rainy day), the question raised, what was the influence of moisture on the different core materials of the six material groups and how would the filter systems deal with the expected high amounts of dust.

Table 32: Basic Information on the Large-scale Test in TP10

Date	23th October 2013
Duration	ca. 2.5 hours (9:30 – 12:00)
Year of construction	2008
Technology	2-shaft and 4-shaft shredder, bag house filter, pelletizer for PU foam, cryogenic technology
Throughput	55 – 60 appliances per hour

For this test, six refrigerators had been prepared with the corresponding amount of panels for each of the six material groups. To guarantee, that the plant would only deal with VIP-containing plants during the test period (to represent a worst case scenario), the plant had been totally cleaned before the test. The pelletizer, which is designed to press the PU foam particles into pellets, was deactivated for the whole test period. Actually, the panels should be treated again in ascending order, but in this case, MG2 was treated as last material group. This was, because while sorting the panels, it seemed, as if there were no MG2 panels, but finally they have been found. The following subchapters deal with the performed tests of each material group and contain the results of every run.

a) Material Group 1 – Paper Like

Six refrigerators with 24 MG1 panels in total of different sizes were prepared for the first run of the test (see Figure 33 and Figure 34). The ferrous as well as the non-ferrous output did not show any changes compared to normal operation. Hence, there was assumed that the components of the VIPs went in the PU output, as usual. This could not be confirmed until the end of the test. Table 33 gives a summary of the test with MG1 in TP10.

Figure 33: Panels of MG1 (TP10)

Figure 34: Appliances Filled with MG1 Panels (TP10)

Table 33: Basic Information on MG1's Test in TP10

Number of appliances	6 appliances
Number of panels	24 panels (various sizes)
Duration	ca. 20 minutes (10:10 – 10:30)
Result	no technical problem for the plant; all VIPs' components (aluminium foil as well as core material) in PU output;

b) Material Group 3 – Glass Wool Like

24 panels of MG3 of different sizes were distributed among six appliances (see Figure 35 and Figure 36) and put in the plant. The quality of the output materials remained unchanged. In Table 34 some basic information on the test with MG3 is summarised.

Figure 35: Panels of MG3 (TP10)

Figure 36: Appliances Filled with MG3 Panels (TP10)

Table 34: Basic Information on MG3's Test in TP10

Number of appliances	6 appliances
Number of panels	24 panels (various sizes)
Duration	ca. 15 minutes (10:25 – 10:40)
Result	no technical problem for the plant; all VIPs' components (aluminium foil as well as core material) in PU output;

c) Material Group 4 – Grey Powder

Although six appliances had been prepared with each four panels of MG4 (see Figure 37), it was decided – due to the experiences with this material group in the TP1n plant – to start with only three appliances at once. These three appliances were enough for causing an enormous amount of dust, spread in the entire plant building. As a consequence, the remaining appliances were not fed. In chapter g) the formation of dust is documented by several photos and in **Error! Reference source not found.** a summary on the test with MG4 is given.

Figure 37: Panels of MG4 (TP10)

Table 35: Basic Information on MG4's Test in TP10

Number of appliances	3 appliances
Number of panels	12 panels (various sizes)
Duration	ca. 10 minutes (10:40 – 10:50)
Result	heavy formation of dust (see chapter g)); all VIPs' components (aluminium foil as well as core material) in PU output;

d) Material Group 5 – Brown Powder

The core material of the MG5 panels (see Figure 38) is physically and chemically similar to MG4's core material. Due to the heavy formation of dust in the building of the plant, it was decided, that only three appliances with twelve panels of MG5 should be treated. This decision was supported by the effect, that also MG5 caused a huge amount of dust. In Table 36 the basic information about the test with MG5 is summarised.

Figure 38: Panels of MG5 (TP10)

Table 36: Basic Information on MG5's Test in TP10

Number of appliances	3 appliances
Number of panels	12 panels (various sizes)
Duration	ca. 10 minutes (10:54 – 11:05)
Result	heavy formation of dust (see chapter g)); all VIPs' components (aluminium foil as well as core material) in PU output;

e) Material Group 6 – Black Powder

Considering that MG4 and MG5 (both powdery core materials like MG6) caused formation of dust in the plant, only three refrigerators with four panels of MG6 each (see Figure 39) were tested. The assumption, that also MG6 panels would provoke an emission of dust, was confirmed (see chapter g)). The core material showed magnetic characteristics and was for that reason also found in the ferrous output as thin layer on the iron pieces. However, the VIP components' majority went to the PU output, like the components of the other VIPs. Table 37 gives an overview of the test with the MG6 panels in TP10.

Figure 39: Panels of MG6 (TP10)

Table 37: Basic Information on MG6's Test in TP10

Number of appliances	3 appliances
Number of panels	12 panels (various sizes)
Duration	ca. 10 minutes (11:06 – 11:15)
Result	heavy formation of dust (see chapter g)); majority of VIPs' components (aluminium foil as well as core material) in PU output; thin layer of core material in ferrous output (due to magnetic characteristics);

f) Material Group 2 – White Fleece

The panels of MG2 were fed at the end of the test. Therefore, this material group was tested as last material. As a fact there were only a few panels of MG2 available, only three refrigerators were filled with 15 small panels. During the shredding process of MG2, the amount of dust in the building was decreasing. Some basic parameters the test of MG2 is summarised in Table 38.

Table 38: Basic Information on MG2's Test in TP10

Number of appliances	3 appliances
Number of panels	15 small panels
Duration	ca. 10 minutes (11:17 – 11:30)
Result	decrease of formation of dust (see chapter g)); majority of VIPs' components (aluminium foil as well as core material) in PU output;

g) Summary of the Large-scale Test in TP10

Except MG2, the six material groups were treated in the TP10 plant in ascending order. While shredding MG4, MG5 and MG6, a heavy amount of dust spread inside the plant building, which is obvious in Figure 40. The photo demonstrates the dust layer on the band conveyor.

Figure 40: Formation of Dust in Building of Plant during Shredding of MG4, MG5 and MG6.

These previous pictures illustrate, that the present plant, TP10,is not ready for treating the powdery VIPs in huge amounts. Some modulations (better dust filter systems, bigger exhaust air flow etc.) would be necessary to make the plant ready for MG4, MG5 and MG6. After the three powdery material groups, MG2 was treated as last test material. While the shredding process of MG2, the amount of dust inside the plant was decreasing; although some dust particles wafted through the air, which were visible in flash light. After all VIPs of the six material groups had been treated in the plant, it was possible to stop the plant and open the filters. There, as assumed, the VIPs' components together with the PU foam were found.

Figure 41: Residue on the Filter directly behind the Shredder

The amounts of the residue of the filter directly behind the shredder (see Figure 41) were according to the production manager clearly bigger than the dust amounts of a normal operation. It was a mixture of PU foam and core materials of the VIPs. This mixture was also found in the PU silo (see Figure 42).

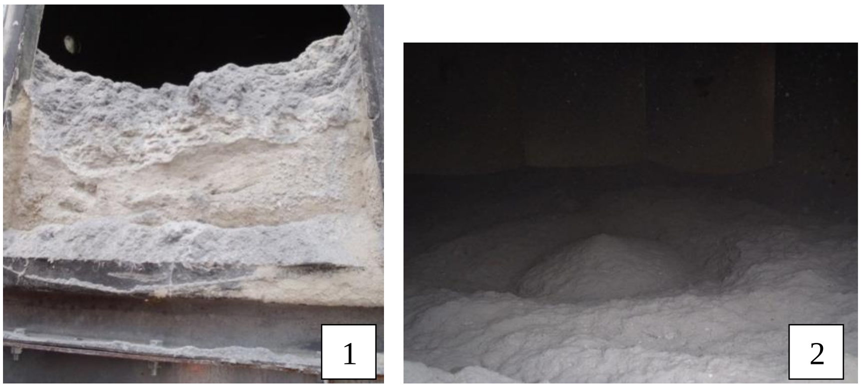

Figure 42: PU Output Mixed up with VIPs' Components
(1: Layers of different Materials; 2: Interior of PU Silo)

Due to the deactivation of the PU pelletizer, it was not possible to test, how the mixture of PU and VIP material would react in the pelletizer and if it was possible to pelletise the material. In Table 39 a summary of the test in TP10 plant is given.

Table 39: Summary of the Large-scale Test in TP10

Number of appliances in total	24 appliances
Number of panels in total	99 panels (various sizes, 6 different material groups)
Duration	ca. 2.5 hours (9:30 – 12:00)
Result	MG1 and MG2: no technical problem for the plant; MG4, MG5 and MG6: heavy formation of dust inside the building of the plant, only half of planned material was

	treated; MG2 (last test material): decrease of dust; majority of VIPs’ components (aluminium foil as well as core material) in PU output; thin layer of MG6’s core material in ferrous output (due to magnetic characteristics);

V. Summary and Conclusions

In this chapter, the most important results, which were gained within the framework of the project, are summarised. Finally, recommendations for the future concerning the recycling of VIP-containing refrigerators for both, the household appliances producers and the recyclers, are given.

1. General Information on VIPs

Vacuum insulation panels are used in the construction of cooling and freezing appliances (mainly appliances of energy class A++ and A+++) since about 2010. By using these high performance thermal insulations, with better insulation properties (lower thermal conductivity) compared to the commonly used PU-foam, an increase of the appliances' storage volume can be achieved. The main components of a vacuum insulation panel are:

- Multilayer envelope (prevention of air inlet);
- Highly-porous core material, e.g. fibreglass (stabilisation against atmospheric pressure);
- Getters (collection of gases leaked through the membrane to ensure vacuum);

In this project, six different material groups of VIPs (concerning the core materials) were identified and tested. In Table 40 the results of the XRF analysis of these six material groups (MG1 – MG6) are summarised. It is obvious, that silicon dioxide (SiO_2) is the main component of all VIPs, although MG4, MG5 and MG6, consisting of a powdery core material, have even a higher percentage of SiO_2 than MG1, MG2 and MG3. All material groups show a high percentage of inorganic materials.

Table 40: Basic Information on the Chemical Composition of the Six Material Groups

Compound/ Chemical Formula	Weight [%]					
	MG1 paper like 	**MG2** white fleece 	**MG3** glass wool like 	**MG4** grey powder 	**MG5** brown powder 	**MG6** black powder 
Silicon dioxide (SiO_2)	69.08	54.08	51.03	98.01	88.00	71.12
Calcium oxide (CaO)	8.81	24.97	30.13	-	-	-
Aluminium oxide (Al_2O_3)	-	13.57	14.10	-	-	-
Iron(III) oxide (Fe_2O_3)	-		-	-	-	22.41
Sodium oxide (Na_2O)	14.09	-	-	-	-	-
Sum of organic material	0.27	2.76	1.22	1.19	5.98	3.15

2. Small Technical Tests

Based on the performed small-scale tests (shredding tests and sieving analyses) and the chemical analyses of the six material groups, basic information on the materials' properties could be gained. This was necessary to determine possible health and safety conditions at the recycling plants for the large-scale tests.
First of all, the panels of all six material groups were shredded by a four-shaft shredder. The shredded material (<25 mm) of each material group was transported by a band conveyor into buckets, where it was collected separately. The material groups MG1 to MG5[3] were investigated by sieving analyses. The question was, whether a separation of aluminium (envelope) from the core material by sieving would be possible. Because the core materials of MG1, MG2, MG3 and MG4 were chemically analysed by an XRF analysis, the core materials had to be prepared/grinded with the help of a ball mill, to ensure that the material is homogenous and powdery.

Every carried out step of the small-scale tests had some challenges, e.g. the suitability for shredding or conveying materials during the shredding test. The challenges of each performed step and the results are summarised in Table 41.

Table 41: Challenges and Ratings of the Material Groups during Small-scale Tests

Challenges \ Material Group	MG1	MG2	MG3	MG4	MG5	MG6
Suitability for Shredding	↑	↑	o	↑	↑	↑
Suitability for Conveying	↑	↑	↑	o	o	o
Formation of Dust	↓	o	↓	↑	↑	↑
Difference between dry and humidified Sieving Analysis	↑	o	↑	o	o	/
Effort for Grinding Core Materials for XRF-Analyses	↓	↓	↑	o	/	/

Legend: ↑…high; **o** …moderate; ↓…low;

3. Mass Balances of Appliances

According to Annex V of WEEE directive 2012/19/EU 80% of C&F appliances shall be recovered and 75% shall be recycled until August 2015. From August 2015 on, both the recovery as well as the recycling rate should be increased by 5%, which means that 85% shall be recovered and 80% shall be prepared for re-use and recycling.

To guarantee the required recycling and recovering rates by the WEEE directive, it is necessary to use (mainly) materials in the construction of the appliances, which are suitable for these challenges. For a material recycling, a market for the materials is required.

A comparison of mass balances between VIP-containing refrigerators (see Table 42) and common refrigerators without VIPs (see Table 43) shows, that the utilisation of VIPs does not cause a big impact concerning the recyclability of the appliance, although the composition of

[3] Due to the characteristics of MG6, being very powdery and dusty, MG6 was excluded from a sieving analysis.

the refrigerators is different.

Table 42: Calculation of Possible Recycling and Recovery Rates of a Modern Refrigerator with VIPs

INPUT in Recycling Plant				
Refrigerator with VIPs	**ca. 80 kg**		**100%**	
OUTPUT of Recycling Plant				
Metals (ferrous and no-ferrous)	37.6 kg	ca. 47%	mat-rec	**75.5%**
Inorganic material (glass, VIPs)	8.8 kg	ca. 11%	mat-rec	
Sum of plastics (PU, PE, PS etc.)[1]	28 kg	ca. 35%	mat-rec/ ther-rec	**24.5%**
Rest	5.6 kg	ca. 7%	ther-rec	

Legend: mat-rec…material recycling; ther-rec…thermal recovery;
based on data from [Sarc]
[1)] Assumption, that half of plastics fraction is recycling and the other part is incinerated.

Table 43: Calculation of Possible Recycling and Recovery Rates of a Refrigerator without VIPs

INPUT in Recycling Plant				
Refrigerator without VIPs	**52-54 kg**		**100%**	
OUTPUT of Recycling Plant				
Ferrous metals (incl. iron from compressor)	38 kg	ca. 71.3%	mat-rec	**79.8%**
Non-ferrous metals (Al, Cu, Zn, stainless steel and non-ferrous from compressor)	3.4 kg	ca. 6.4%	mat-rec	
Glass	0.7 kg	ca. 1.3%	mat-rec	
CFC/ pentane	0.4-0.5 kg	ca. 0.8%	mat-rec	
Plastics	5-5.5 kg	ca. 9.9%	mat- /ther-rec	**20.2%**
Isolation (PU-foam)	5-5.5 kg	ca. 9.9%	mat- /ther-rec	
Oil	0.2 kg	ca. 0.4%	mat- /ther-rec	

Legend: mat-rec…material recycling; ther-rec…thermal recovery]

4. Large-scale Tests

In October 2013 three large-scale tests were performed in three different recycling plants for end-of-life C&F appliances. By performing the large-scale tests, six material groups were treated together with cooling and freezing appliances, while their influence on the recycling plants was investigated. The selection of the contemplable plants for the test finally led to TP1 (first test), to TP3 (second test) and to TP10 (third test).

In the following tables (Table 44, Table 45 and Table 46) key parameters of the performed large-scale tests in the three different plants is summarised.

Table 44: Key Parameters on First Large-scale Test in TP1

Shredding Unit	four-shaft shredder
Challenges	**heavy formation of dust** during treatment of MG4 → stop of test; cleaning of exhaust air system necessary ;
Output quality changes	**no significant changes**; all VIPs' components (aluminium foil as well as core material) in PU output (used as oil binder);

Table 45: Key Parameters on Second Large-scale Test in TP3

Shredding Unit	cross flow crusher (QZ)
Challenges	increase of Δp at filter 1 during shredding the powdery material groups MG4, MG5, MG6 → **no technical problem for plant**;
Output quality changes	**no significant changes**; all VIPs' components (aluminium foil as well as core material) in PU output (used in cement industry);

Table 46: Key Parameters on Third Large-scale Test in TP10

Shredding Unit	two- and four-shaft shredder
Challenges	**heavy formation of dust** inside the building of the plant during shredding of MG4, MG5 and MG6;
Output quality changes	**no significant changes**; majority of VIPs' components in PU output; thin layer of MG6's core material in ferrous output (due to magnetic characteristics);

Conclusions

Despite the different technologies used in these plants, **general results** regarding the applicability of the state of the art recycling technology for C&F appliances were gained:

- The material groups MG1, MG2 and MG3 react, when being treated in a recycling plant, differently to the powdery material groups MG4, MG5 and MG6 (formation of dust).
- Components of the VIPs go to the PU material, due to similar densities.
- No changes in quality of output material. When the PU foam is used as refuse-derived fuel (RDF) for the cement industry, the VIPs' components (mostly inorganic) are even required, due to the similar chemical composition to the needed raw materials in cement industry.
- The impact of VIPs in recycling plants depends on technology of plant as well as the core material of the VIPs.

In Table 47 key parameters for the major challenges (formation of dust and changes of output quality) of all three large-scale tests are summarised.

Table 47: Summarised Key Parameters of Large-scale Tests

Challenges \ Large-scale Tests	TP1	TP3	TP10
Formation of dust	↑	↓	↑
Changes in output quality	↓	↓	↓

Legend: ↑…high; o …moderate; ↓…low;

5. General Conclusions

The performed tests in this project were supposed to represent a worst-case scenario. When receiving VIPs of MG4, MG5 or MG6, the focus should be on a **high exhaust air rate**, on the **filter systems of the exhaust air** and of course on the **working health and safety conditions**. If more appliances with powdery core materials were treated, some adaptations to the filter system should be done. Due to the occurred mechanical problems with MG3 in the TP1 plant, it also has to be checked, if the plant is able to treat this material without mechanical problems. To prevent any health risks, dust emissions have to be avoided. This precaution measure is relevant for all types of VIPs.

Concerning the output materials, it has to be clear, that the majority of the VIPs' components go to the PU foam. The composition of output materials is, according to the gained experiences, not changed by the VIPs.

It can be expected, that the amount of appliances, which contain VIPs, will increase in the next years, because VIPs were firstly used in the construction of C&F appliances in 2010. That is why every recycler of end-of-life C&F appliances may assess the necessity of adapting its processes and technology to the treatment of VIPs.

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VII. Appendix I: Safety Data Sheet

1. Identification of the substance/preparation and company

1.1. Name of substance/preparation

Commercial product name: Vacuum Insulation Panels

1.2. Use of substance / preparation

Industrial

Thermal insulation

1.3. Company name/Manufacturer(s)

1.4. Emergency telephone number

Emergency Information (Austria):
Office for Emergency Measures +43/(0) 1/4000-75222

Emergency Information (German):
plant fire brigade +49/(0) 8677/83-2222

Emergency Information (internat.):
National Response Center +49/(0) 621/60-43333

2. Hazards identification

2.1. Classification

This product is a non-combustible, non-reactive solid material. Exposure to glass powder or dust released as a consequence of damage to the core materials of Vacuum Insulation Panels (VIPs) may cause mechanical irritation to eyes, skin or upper respiratory tract. Purely mechanical irritation, however, in Europe is not considered a health hazard in accordance with the European Directives 67/548/EEC. This is confirmed by the fact that EC Directive 97/69/EC for fibres does not stipulate the need to use an Xi (irritant) label nor a classification.

There are no known hazards associated with the handling or use of this insulation. Amorphous silica has a drying action on skin.

Dust produced from core insulation may, like any other dust, aggravate pre-existing upper respiratory and lung diseases.

Exposure of the panels to high temperatures, however, will result in the emission of smoke, and decomposition/combustion products.

2.2. Further Information

Owing to the length: diameter ratio, the fibres cannot enter the lungs (drawn continuous filament with diameter >6 µm according to Directive 67/548/EWG Note R & Directive 97/69/EC Note Q.

3. Composition/information on ingredients

3.1. Chemical characterization (substance)

Chemical Name	CAS-Number	EC Number	%
Amorphous silica	112945-52-5	31-545-4	50 to 100%

Calcium silicate	1344-95-2	235-336-9

4. First-aid measures

4.1. General information:

In case of accident or if you feel unwell seek medical advice (show label or SDS where possible).

4.2. After inhalation

Provide fresh air.

4.3. After contact with the skin

Rinse affected areas with water, taking care not to scratch or rub. Seek medical attention if irritation persists.

4.4. After contact with the eyes

Flush immediately with copious amounts of water. Do not rub eyes. Seek medical attention if irritation persists.

4.5. After swallowing

In the event of suspected problems, seek medical attention.

5. Fire-fighting measures

Product does not burn. Use extinguishing measures appropriate to the source of the fire.

5.1. Suitable extinguishing media

not applicable

5.2. Extinguishing media which must not be used for safety reasons

not applicable

5.3. Special exposure hazards arising from the substance or preparation itself, combustion products, resulting gases

not applicable

5.4. Special protective equipment for fire fighting

not applicable

6. Accidental release measures

6.1. Personal precautions

Avoid dust formation. Do not breathe dust. Wear personal protection equipment

6.2. Environmental precautions

Cover any spilled material in accordance with regulations to prevent dispersal by wind.

6.3. Methods for cleaning up

Damp down dust and fill into containers.

7. Handling and storage

7.1. Handling

Avoid dust formation.

Electrostatic discharge is possible during transport and processing. Take precautionary measures against electrostatic charging. Ensure all parts of equipment are well earthed. Use inert gas when working with combustible and explosive liquids. Avoid dust deposit, remove dust regularly.

7.2. Storage

Should bed stored in dry conditions. Store in a cool, dry, ventilated area away from sources of heat, moisture and incompatibilities. Protect product from physical damage.

Protect from weather and prevent exposure to sustained moisture.

8. Exposure controls and personal protection equipment

8.1. Exposure limits

UK "EH 40/02 Occupational Exposure Limits 2002"

Published by the Health and Safety Executive

TOTAL INHALABLE DUST	RESPIRABLE DUST
(8-hour time weighted average reference period)	
Amorphous silica 6 mg/m^3 [OES]	Amorphous silica 2.4 mg/m^3 [OES]
Silicon carbide 10 mg/m^3 [OES]	Silicon carbide 4 mg/m^3 [OES]

[OES]….Occupational Exposure Standard

GERMANY: "List of MAK Values" for maximum concentrations at the Workplace.

TOTAL INHALABLE DUST	RESPIRABLE DUST
(8-hour time weighted average reference period)	
Amorphous silica 4 mg/m^3	Silicon carbide 1.5 mg/m^3
General dust limit 10 mg/m^3	General dust limit 3 mg/m^3

CAS-Nr. (Amorphous silica) 7631-86-9 and 112945-52-5
EG-Nr. (Amorphous silica) 231-545-4

8.2. Exposure limited and controlled

8.3. Exposure in the work place limited and controlled

General protection and hygiene

Measures: Do not breathe dust. Do not eat, drink or smoke when handling. Application of skin cream recommended to ensure optimum protection of skin.

Personal protection equipment Respiratory

Protection: In case of dust formation: fine dust mask without protection rating.

Hand protection	Recommendation: rubber gloves
Eye protection	Recommendation: protective goggles
Skin protection	antistatic working shoes

9. Physical and chemical properties

9.1. General Information

Physical state / form:	solid – powder /
	white cloth covered panels /
	silvery film
Colour:	white /
	black powder (inside) /
	grey powder
Odour:	odourless /
	neutral

9.2. Important information about the protection of health, safety and the environment Method

Melting point / melting range:	core: 1700 °C /
	> 1200°C
	film: 150°C
Boiling point / boiling range:	not applicable
Flash point:	not applicable (on core)
	film: building material B3
Ignition temperature:	not applicable/
	350°C /
	> 150°C
Lower explosion limit (LEL):	not applicable
Vapour pressure:	not applicable
Density:	approx. 2,2 g/cm³ at 20 °C (DIN 51757)
Bulk density:	20 - 130 kg/m³ /
	140 – 210 kg/m³
Water solubility/miscibility:	virtually insoluble at 20 °C
pH-Value:	3,6 - 4,5 (DIN EN ISO 787-9) /
	4,2 – 4,3 at 20°C
Viscosity (dynamic):	not applicable

10. Stability and reactivity

10.1. General Information

If stored and handled in accordance with standard industrial practices no hazardous reactions are known.

10.2. Conditions to avoid

None known

10.3. Materials to avoid

None known

10.4. Hazardous decomposition products

If stored and handled in accordance with standard industrial practices and local regulations where applicable: none known.

The Barrier film used to encapsulate VIPs 'core material will begin to decompose at approximately 150. The thermal decomposition products will vary with temperature and oxygen availability, but could include carbon monoxide.

11. Toxicological information

11.1. General information

According to our present state of knowledge no damaging effect expected when treated in accordance with standard industrial practices and local regulations where applicable.

11.2. Toxicological tests

EXPOSITION	VALUE/VALUE RANGE	SPECIES	SOURCE
oral	5000 mg/kg rat	rat (Limit Test)	literature
dermal	> 5000	rabbit (Limit Test)	literature
by inhalation	> 0,139 mg/l/4h	rat (Limit Test)	literature

EXPOSITION	EFFECT	SPECIES/TESTSYSTEM	SOURCE
To skin	Not irritating	Rabbit	literature
To eyes	Not irritating	Rabbit	literature

11.3. Experience with man

By handling the product for many years no damage to health was observed.

12. Ecological information

12.1. Eco toxicity

SPECIES	TEST METHOD	EXP. TIME	RESULT	SOURCE
Daphnia magna	acute	24 h	> 10000 mg/l (EC50)	literature
zebra fish (Brachydanio rerio)	acute	96 h	> 10000 mg/l (LC50)	literature

No expected damaging effects to aquatic organisms.

According to current knowledge adverse effects on water purification plants are not expected.

It can remove mechanically from waste water.

12.2. Mobility

-

12.3. Persistence and degradability

Biodegradation / further information: Not applicable

Further information: Insoluble in water

12.4. Bio-accumulation potential

No adverse effects expected

12.5. Other harmful effects

-

12.6. Additional information

General information: Insoluble in water

13. Disposal considerations

13.1. Material

Can be disposed of with domestic waste, observe local/state/federal regulations

13.2. Uncleaned packing

Completely discharge containers (no tear drops, no powder rest, scraped carefully). Containers may be recycled or re-used. Observe local/state/federal regulations.

14. Transport information

14.1. Land transport ADR and RID

Road ADR: Not regulated for transport

Railway RID: Not regulated for transport

14.2. Transport by sea IMDG-Code

Not regulated for transport

14.3. Air transport ICAO-TI/IATA-DGR

Not regulated for transport

15. Regulatory information

15.1. Warning Label (EC)

The product is not dangerous, defined by the Chemical law or Hazardous Substances Ordinance.

15.2. National regulations

National and local regulations must be observed.

15.3. Other international regulations

15.4.

16. Other information

16.1. Material

Further information

VIII. Appendix II: Complementary Large Scale Test

Institut für Energie- und Umwelttechnik e.V.
Bliersheimer Straße 58 - 60
47229 Duisburg
Notified body for measurements/tests according to sec. 26, 28 BImSchG
Approved inspection centre within the meaning of TA Luft (Technical Instructions on Air Quality Control) 5.4.8.10.3, 5.4.8.11.3
Approved waste management company

Report: 06-07112013-001

Test processing of refrigeration appliances with vacuum insulation panels (VIP) at the TP5 recycling plant

Test dates:	06/11/2013 to 07/11/2013
Report by	Institut für Energie- und Umwelttechnik IUTA; Duisburg
	H. J. Prause, certified technician (Staatl. gepr. Techniker)
	J. Schiemann, graduate engineer (Dipl. Ing.)
Report date	29/11/2013

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(Addendum:)

The client would like to thank the responsible staff at the recycling plant for their willingness to carry out the trial processing. A thank you also goes to IUTA who has also contributed their knowledge and thus to the success of the trial processing.

1 Preamble

In order to increase their efficiency, refrigeration appliances have for some time used vacuum insulation panels (VIP). These can for example use silicic acid or glass fibre and due to their strong insulating effect, the refrigeration appliances can achieve an efficiency rating of A+++.

On the other hand, this new technology may constitute a challenge for established recycling plants that process old refrigeration appliances.

In order to clarify any potential impact on the recycling processes, a practical trial using carcasses and doors from refrigeration appliances using VIP (according to MG 4 – MG 6 of the CECED trial) was set up to process these appliances in trial batches.

2 Trial date

The trials were held from 9 am on 6 November 2013 to 12 pm on 7 November 2013.

3 Objective

The purpose of the trial was to provide the manufacturer of the refrigeration appliances, with insight into any potential impact of the new generation of refrigeration appliances on the established recycling process.

The aim was to process the refrigeration appliances and observe the parameters and general conditions, in particular, to examine and describe potential emissions, negative impact on the recycling process or pollution by the fractions to be extracted

4 Trial constraints

The trial involved un-used carcasses and doors from appliances manufactured and provided by the manufacturer. TP 5 agreed to carry out the trial processing.

The trials provided snapshots that have limited applicability for the following: appliances from other manufacturers, processing appliances that have been in use for a long time, processing in a different plant or processing using different operating parameters.

The trials were conducted at low temperatures (15 to 18°C) with a relative humidity of 48-56 %.

5 Description of the plant

The plant largely consists of a loading station with a single conveyor belt and an exhaust with nippers, an encapsulated pre-shredder, a second encapsulated shredder, various encapsulated separation units, an encapsulated cryogenic unit and the removal units for the different material streams produced.

The suction table of the Step 1 processing is designed for 10 refrigeration appliances. It has five extraction lines. The table is manned by one person per shift. An EnPro LE 10-2006 is used for extraction and oil separation. Leaked air from faulty cooling circuits is transferred via an activated carbon filter. The load of the filter element is controlled gravimetrically. After purging the cooling circuits, the

compressors are removed using mechanical small tools or hydraulic cutters and the compressors are drilled out. They are subsequently placed on a table where they can empty completely.
The pre-treated refrigeration appliances are fed into a sluice chamber via a lift with a bottom-closing seal and then on to a four-roller shredder of the type RS 100 manufactured by Untha in 2003. The gas in the lifting and shredding chambers is continuously extracted (50m³/h; 80m³/h). The sluicing chamber is continuously supplied with cleaned process air and the shredding chamber has an inerting system that is used according to the needs.
The shredded material (0 to 50 mm particle-size distribution) is then fed into a cross-flow shredder (manufacturer: Heckert) via a screw conveyor. The gas in this shredder is continuously extracted (80m³/h) and is constantly inerted with nitrogen. All major rooms where process gas is carried are equipped with sensors monitoring the oxygen and hydrocarbon content.
The subsequent separation of materials is done with a zig-zag air separator for light parts and a magnet above the conveyor belt for ferrous metals. The insulation foam fraction is separated from the plastic parts before discharge using cyclonic separation. The individual fractions are subsequently discharged into containers.
The controlled standard amount of air extracted from the encapsulated aggregates is approx. 300 m³/h and is cleaned using a cryogenic unit (Duo Condex 3000 manufactured by Messner).
The plant has measuring equipment (manufacturer: Fresenius, measurement parameters R 11 and R 12) to measure pure gas.

6 Inspection and initial measurements

The plant was inspected prior to the trials. The complete operating process corresponded to regular operations. The use of VIP does not affect Step 1 processing. The trials were limited to Step 2 processing.
The trial appliances were sluiced between the two processing steps without any problems. There is sufficient space to carry out any sorting of appliances pre processing.
The foam insulation in the trial appliances was made of polyurethane (PUR) and the blowing agent pentane. The plant is able to process such foam insulation.
The lift used to load the appliances was of adequate size. The trial appliances were refrigeration/freezer appliances with standard measurements. Based on the volume and mass of the appliances, there seemed to be no issue processing them at the plant. The stability and complexity of the trial appliances was not meant to put any increased requirements on the shredding and sorting of the materials produced.

The assumption is made that the materials contained in the VIP are released as fine particles. Conventional technology may not be able to control these emissions adequately and for this reason, the plant was thoroughly examined for potential emissions prior to the trials.
At Step 2, doors, service hatches, drip trays, material feed and removal components as well as all system parts with air containing CFCs were subjected to particular scrutiny.

For this purpose, the following measuring devices were used:

Ambient air:

Manufacturer	Devices	Detection limit
ppm Messtechnik	MAC 2040 R 11	1 mg / m³ (up to max 100 mg/m³)

Plant parts:

Manufacturer	Devices	Detection limit
ppm Messtechnik	MAC 2240 R 11	1 mg / m³ (up to max 3,000 mg/m³)

Leakage detection:

Manufacturer	Devices	Detection limit
Refco	Startek	< 3g / year R 11, R 12, R 22, R 134a

The measurement principle of the MAC devices as well as that of the gas sensitive semiconductor are recommended in the guidelines for checking the gas tightness according to TA Luft [*Technical Instructions on Air Quality Control*] 5.4.8.10.3 and 5.4.8.11.3.

Dust:

Manufacturer	Devices	Detection limit
Grimm	Model no. 1.108	0,3 µm to > 20 µm

The dust measuring device can be used to continuously measure dust particles in the air and their aerosol distribution. The measurements for particle concentration are provided in the unit particles/litre. The device uses scattered light measurements of the individual particles. The result can be classified into different size channels (15 channels) and evaluated.

All devices underwent functionality tests prior to the trials.

The following plant areas were identified for initial quantitative measurements to limit potential emission points:

- General air in the hall
- Appliance loading, at the bottom (bottom of lift)
- Appliance loading, top (near door)
- Pre-shredder, lower housing
- Screw conveyor after pre-shredder
- Cross-flow shredder room
- Zig-zag air separator
- Material separation.

In order to create boundary conditions for the tests, the general ambient air was checked using a measuring device (MAC 2040). The measurements were evaluated taking into account the absolute size and height of the room as well as the ventilation.

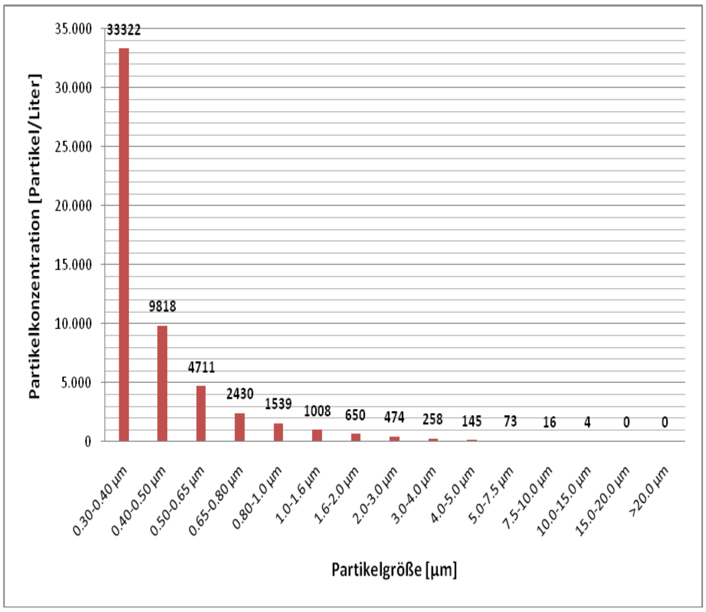
The above-mentioned plant components were also subjected to further quantitative measurements (MAC 2240). These measurements were also evaluated taking into account the absolute size and height of the room and the ventilation.

The following results were derived from the measurements:

Location 1	general air in the hall	no particular indication
Location 2	appliance loading bottom	indication of possible emissions
Location 3	appliance loading top	indication of possible emissions
Location 4	pre-shredder, lower housing	no particular indication
Location 6	screw conveyor after pre-shredder	no particular indication
Location 7	cross-flow shredder room	no particular indication
Location 8	zig-zag air separator	no particular indication
Location 9	material separation	no particular indication

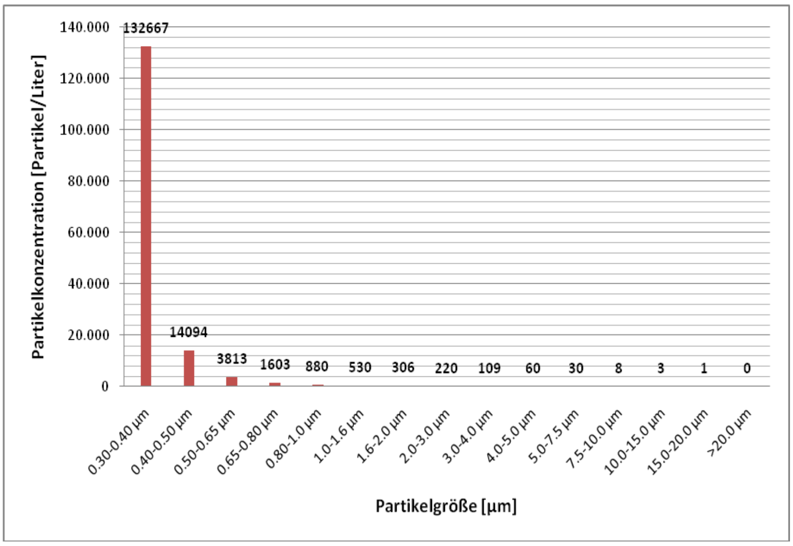
The dust measuring device was subsequently positioned where the highest load of dust deposition was expected.
The amount of dust and the particle-size distribution determined by the measurements can be considered a background pollution for a refrigeration appliance recycling plant at normal operating conditions and used in calculations using the results from the processing of the trial appliances.

Location 1 Screw conveyor to cross-flow shredder



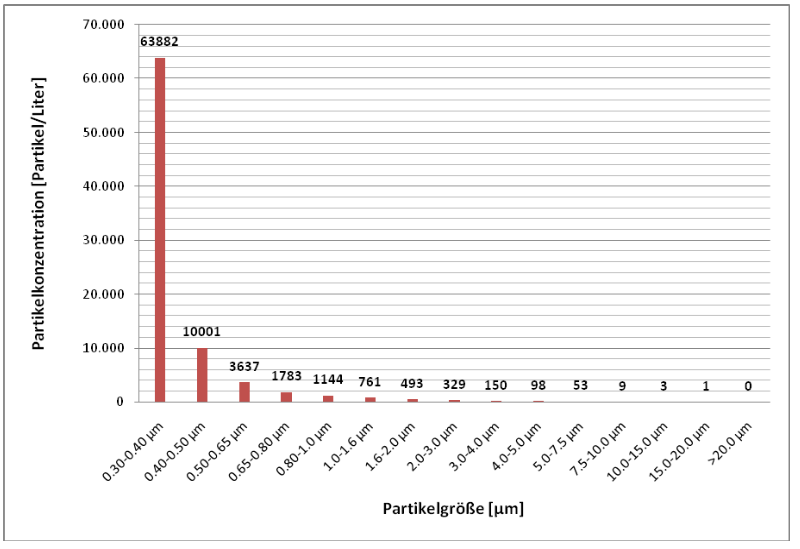
The chart shows half-hour averages.

Location 2 Pre-shredder, bottom



The chart shows half-hour averages.

Location 3 Conveyor, top



The chart shows half-hour averages.

Before processing began, the fraction produced by the pre-shredder to the screw conveyor to the cross-flow shredder was sampled and inspected. The dust filter of the cross-flow shredder was opened and inspected and the wet filter sampled and inspected.

7 Description of processing of Batch 1

At first a trial run consisting of a mono-batch of refrigeration appliances with VIP was put together.

The old refrigeration appliances with VIP processed in this trial stem from warehouse stock. No appliances had been used and they had been collected at the premises of the facility in the preceding 12 months. The appliances were of different models. The cooling circuits of the appliances were not completely assembled. Wire shelves, glass shelves and other accessories were not present. Some appliances had minor corrosion damage on the edges. The insulation of all the inspected appliances seemed to be in good condition with no damage. The doors were not attached, however, there were a large number of individual doors in stock. All carcasses and doors contained VIP, however, there was not information on how many VIP each appliance had, how large they were or where they were located. Some appliances underwent a more thorough inspection. The carcasses that were inspected had walls with foam insulation; the area with the freezer compartment had thicker insulation. The area was not opened with force for safety reasons as it was assumed that this was where the VIPs were located.

Furthermore, several doors were opened up and large VIPs were found. These VIPs were not surrounded by foam and it was therefore presumed that these doors came from laboratory tests (adhesive tests).

Appliance loading (bottom)

All other appliances were sluiced in between the Step 1 and Step 2 plants and fed to the appliance loading. A door, also with VIP, was added to approximately 80% of appliances. Packages of 3 to 4 doors were assembled and added to every four to five appliances. The plant throughput was approximately 30 appliances per hour.

The space above the shredder as well as the lift room (after each opening operation) and the surroundings of the lift room were mainly observed using a camera.

During the first few seconds of shredding the individual appliances with VIP no particular anomalies were observed. After the appliance was completely drawn in, “misting”, similar to what can be observed when very damp appliances are processed, was observed in the shredder room. This “misting” remained largely constant throughout the trials. From about the third or fourth appliance to be processed, vapour emissions were observed in the lift room. Measurements of air humidity in the hall and immediately in the vapours detected lower humidity in the vapours than in the rest of the hall. This led to the dust measuring device being repositioned to immediately next to the lift unit.

Furthermore, the output material was sampled at regular intervals.

During processing a significant increase in dust pollution was observed.

After processing approx. 10 to 12 appliances/door packages, the air line from the pre-shredder to the pentane sensors had to be cleaned. This had to be repeated after a further 10 to 12 appliances.

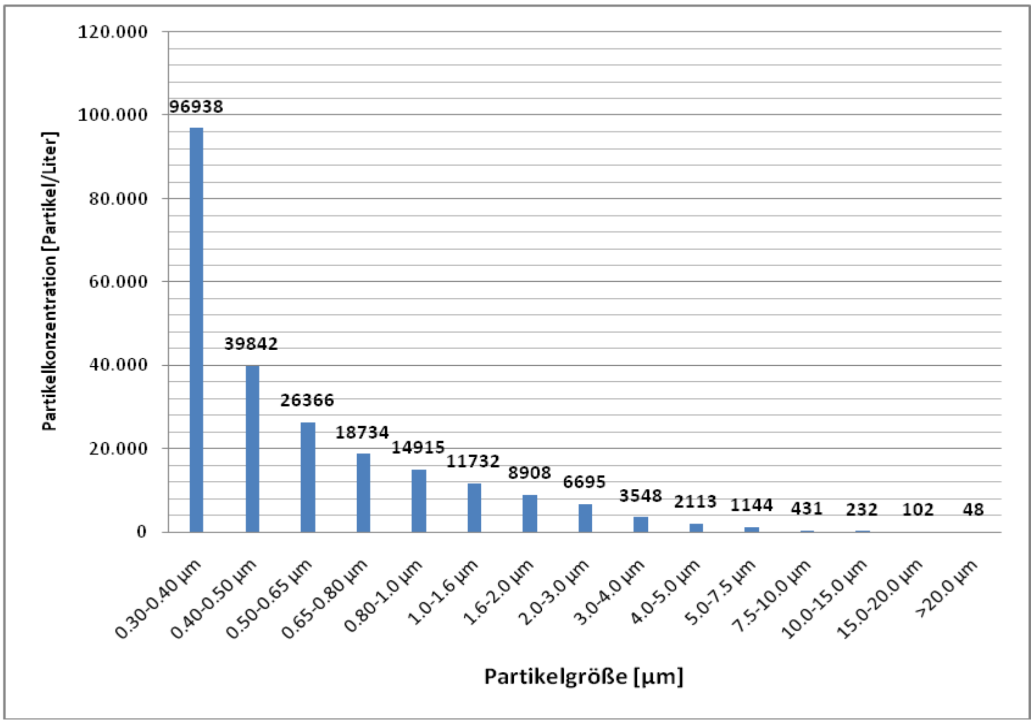
The loading with door packages was therefore stopped as one package of doors contained three to four VIP compared to 2 VIP in one refrigeration appliance. The loading of one door onto an appliance was also discontinued.
A change or decrease in dust pollution was not visually perceived, however, the sensor lines were no longer blocked.

After approximately 5.5 hours the trial processing was completed and the plant thoroughly cleaned in preparation for another batch.

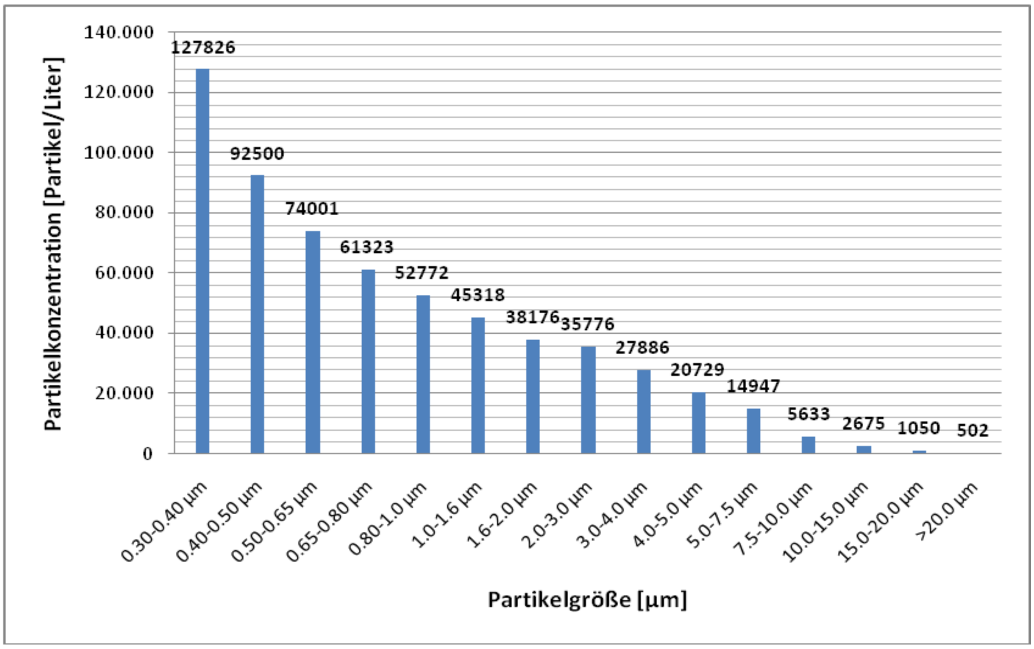
8 Dust measurements during processing of Batch 1

Location 3, lift top, was selected for the dust measurements.

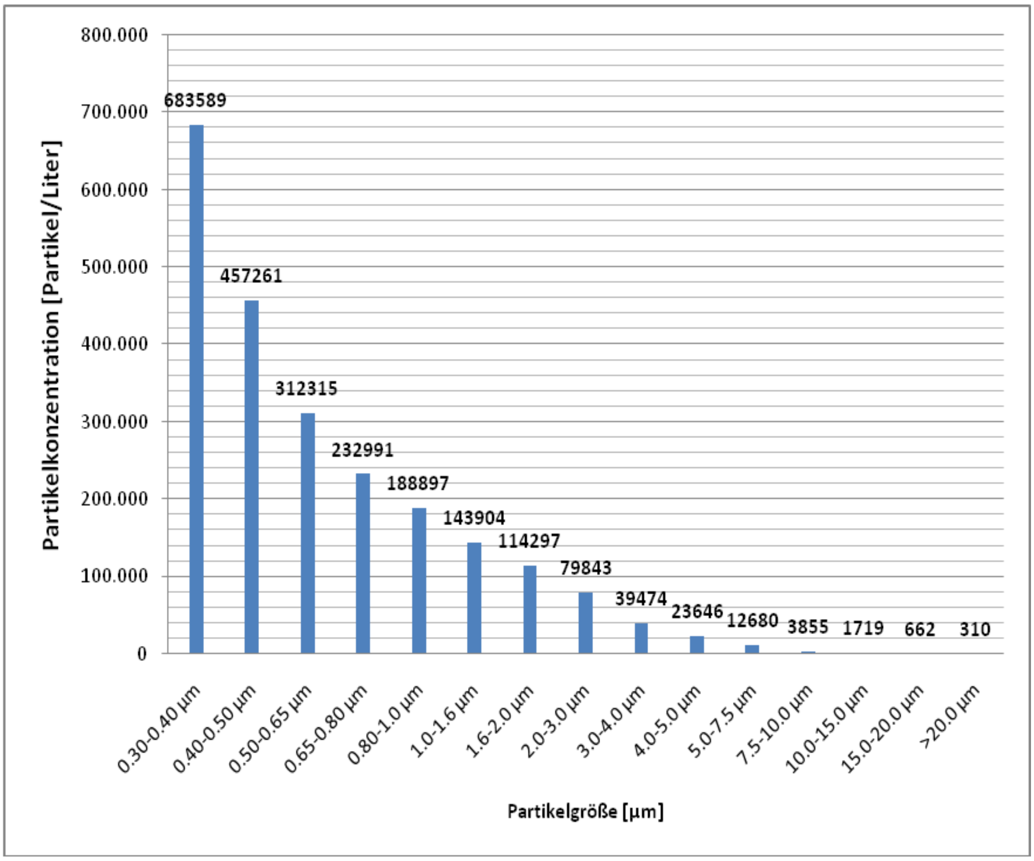
The chart below shows the averaged measurements during a time period of 2 minutes after the processing of approx. 10 to 15 refrigeration appliances with VIP.



The chart below shows the averaged measurements during a time period of 2 minutes after the processing of a further 10 to 15 refrigeration appliances with VIP.

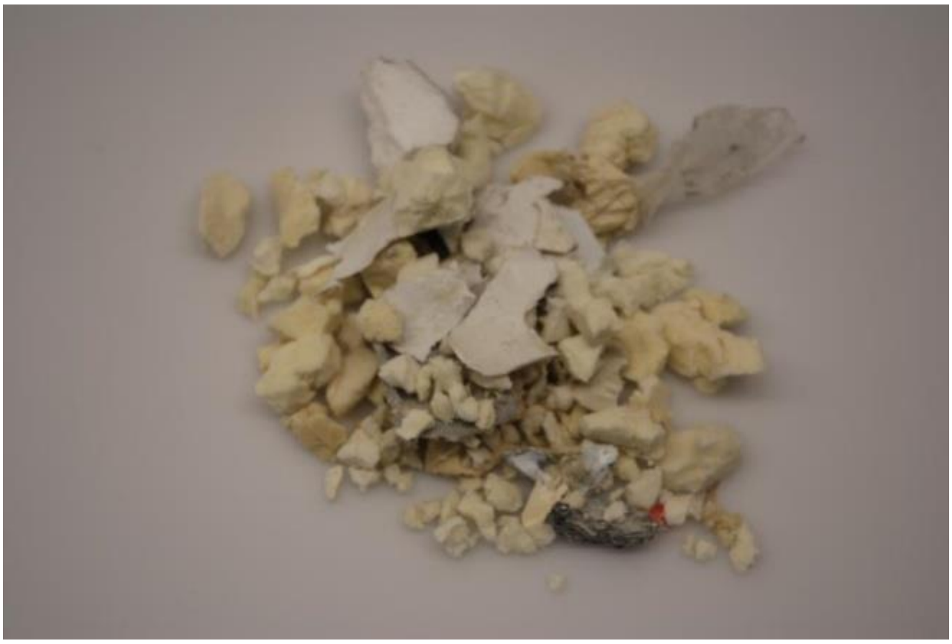


The chart below shows the averaged measurements during a time period of 2 minutes shortly before the end of processing of Batch 1.



9 Material inspection after processing of Batch 1

Samples were taken from different parts of the plant prior to the trial.



Sample 1 prior to trial. Sample taken at: screw conveyor after pre-shredder

Sample 2 prior to trial. Sample taken at: screw conveyor cross-flow shredder

The visual appearance of the material corresponds to conventional observations.

Further samples were taken at the same location after processing approx. 20 to 30 refrigeration appliances with VIP.

Sample 3 after 20 to 25 refrigeration appliances with VIP. Sample taken at: screw conveyor after pre-shredder

Sample 4 after 20 to 25 refrigeration appliances with VIP. Sample taken at: screw conveyor cross-flow shredder

The samples clearly show colouring due to the VIP material contained therein/attached thereto.

10 Description of processing of Batch 2

On the second trial day, a mixed batch of refrigeration appliances with and without VIP was assembled and processed.

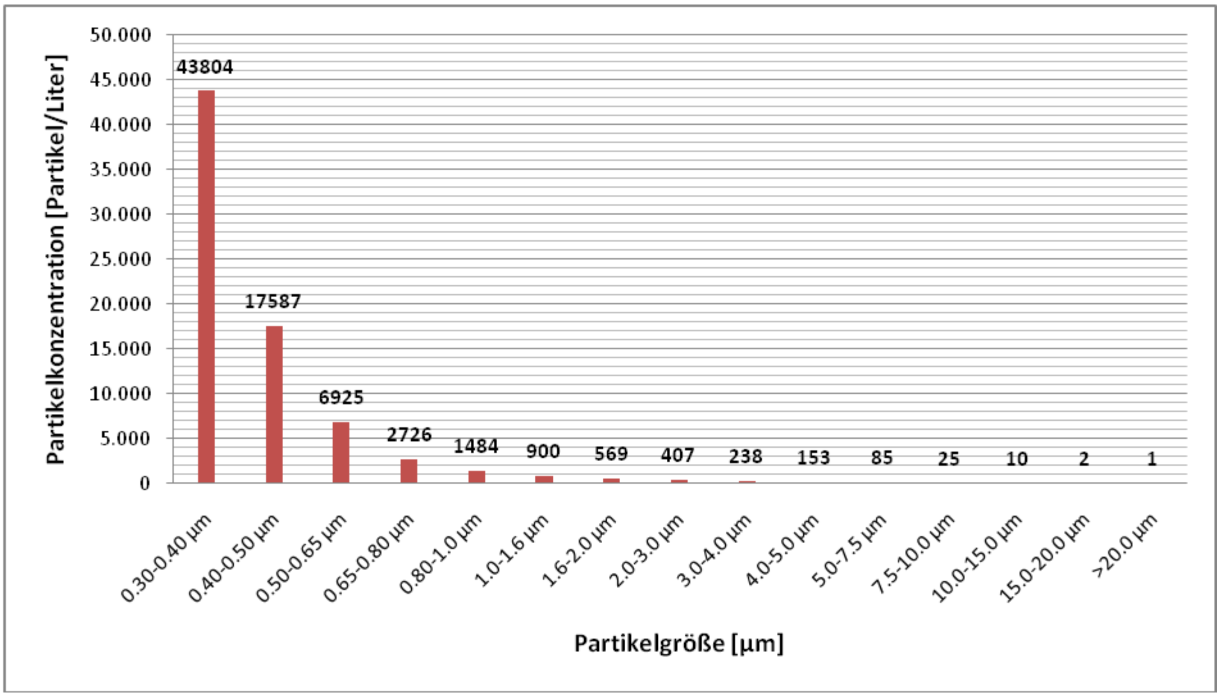
The old refrigeration units with VIP processed in this trial came from the above-mentioned stock; the appliances without VIP were taken from the ongoing processing at the plant. These represented an average of the refrigeration appliances due to be processed. The cooling circuits had already been removed, as had the majority of wire and glass shelving and other accessories. Most appliances still had the doors attached.

The plant was then fed mostly conventional appliances, with appliances with VIP added at defined ratios: 1:10, 1:7 and 1:5. The plant throughput was approximately 30 appliances per hour.

11 Dust measurements during processing of Batch 2

The second trial day also started with a baseline measurement in order to determine the reference values.

Once again Location 3, lift top, was selected.



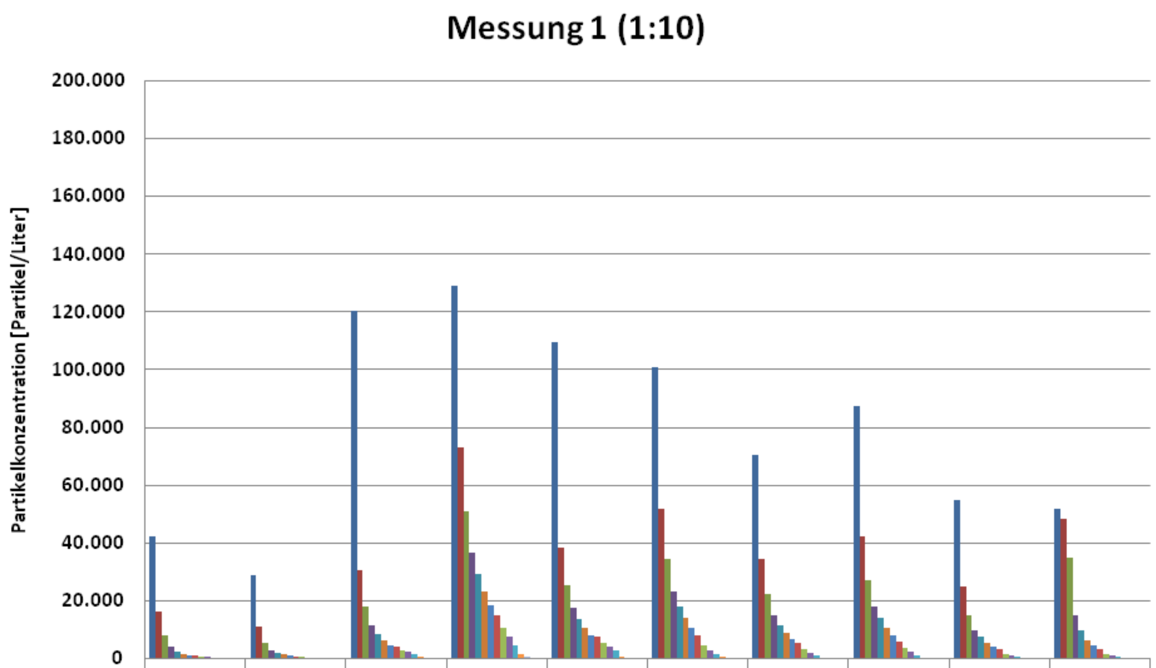
The chart shows half-hour averages.

The objective of processing refrigeration appliances with and without VIP at different ratios was to provide insight into the processing possibilities of real-life volumes and combinations.

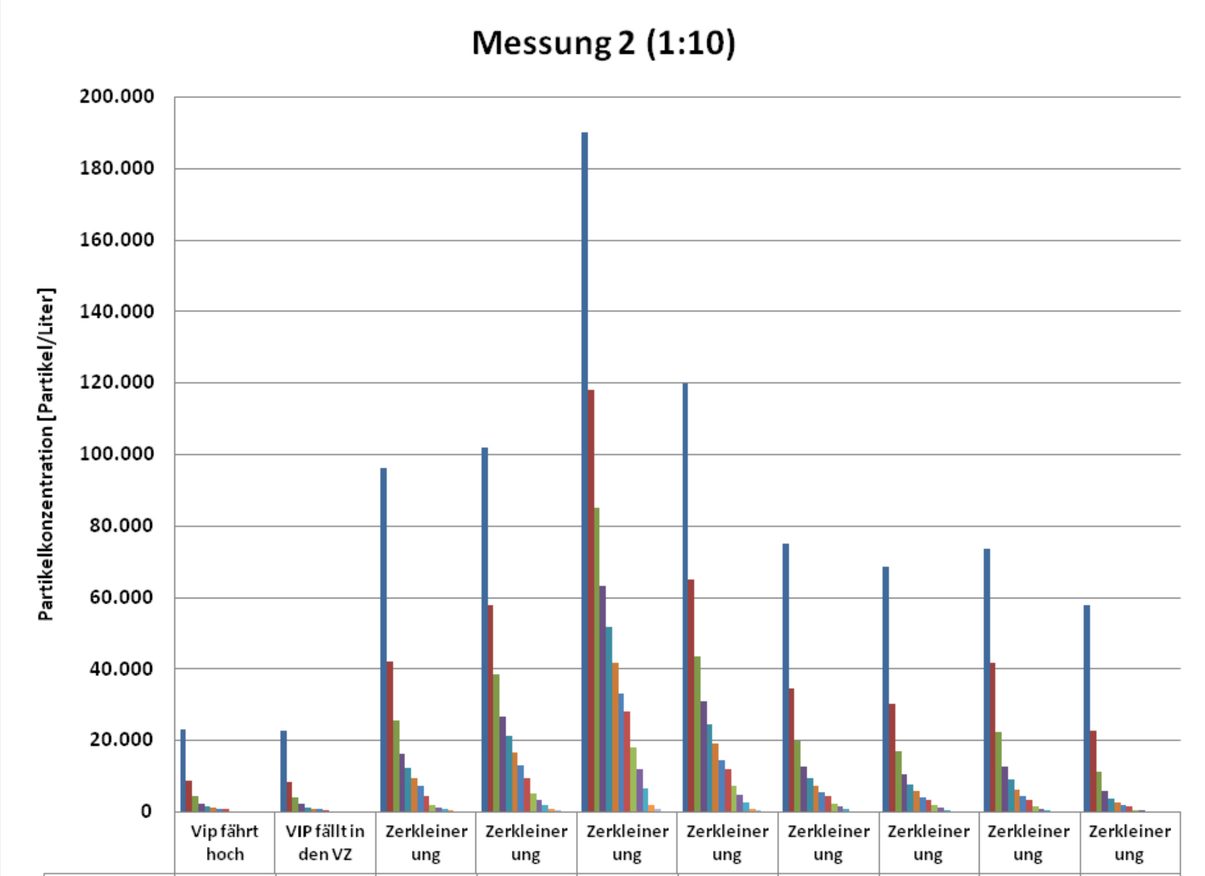
The following charts thus no longer focus on the maximal amounts of emitted dust, but rather on the time resolution of the emission and their decay curves.

The following two charts show the emissions when processing 1 VIP to 10 conventional refrigeration appliances.

The first chart shows the emissions during the first processing run, the second one the last processing run with the combination ratio.



	Vip fährt hoch	VIP fällt in den VZ	Zerkleinerung	Zerkleinerung	Zerkleinerung	Zerkleinerung	Zerkleinerung	Zerkleinerung	Zerkleinerung	Zerkleinerung
0.30-0.40 µm	42236	29037	120379	129207	109360	100626	70376	87184	55055	51888
0.40-0.50 µm	16072	10986	30604	73175	38503	51879	34505	42404	24997	48493
0.50-0.65 µm	7913	5566	18061	50788	25565	34303	22363	27119	15173	34798
0.65-0.80 µm	4046	3014	11484	36841	17744	23371	15042	18168	9876	15044
0.80-1.0 µm	2570	2002	8301	29152	13790	18146	11539	13973	7476	9563
1.0-1.6 µm	1718	1429	6227	23145	10689	13928	8816	10668	5575	6327
1.6-2.0 µm	1209	1020	4755	18462	8218	10595	6516	7858	4111	4342
2.0-3.0 µm	1059	777	3919	14849	7413	8017	5307	5995	3150	3220
3.0-4.0 µm	718	450	2807	10775	5423	4631	3332	3529	1659	1698
4.0-5.0 µm	469	278	2186	7664	3985	2921	2115	2174	960	1084
5.0-7.5 µm	280	158	1377	4536	2890	1594	1185	1168	480	537
7.5-10.0 µm	101	44	519	1528	800	483	379	339	107	148
10.0-15.0 µm	40	15	248	634	264	167	150	123	35	60
15.0-20.0 µm	14	4	88	202	61	47	52	33	10	14
>20.0 µm	6	1	49	97	28	23	25	17	6	7

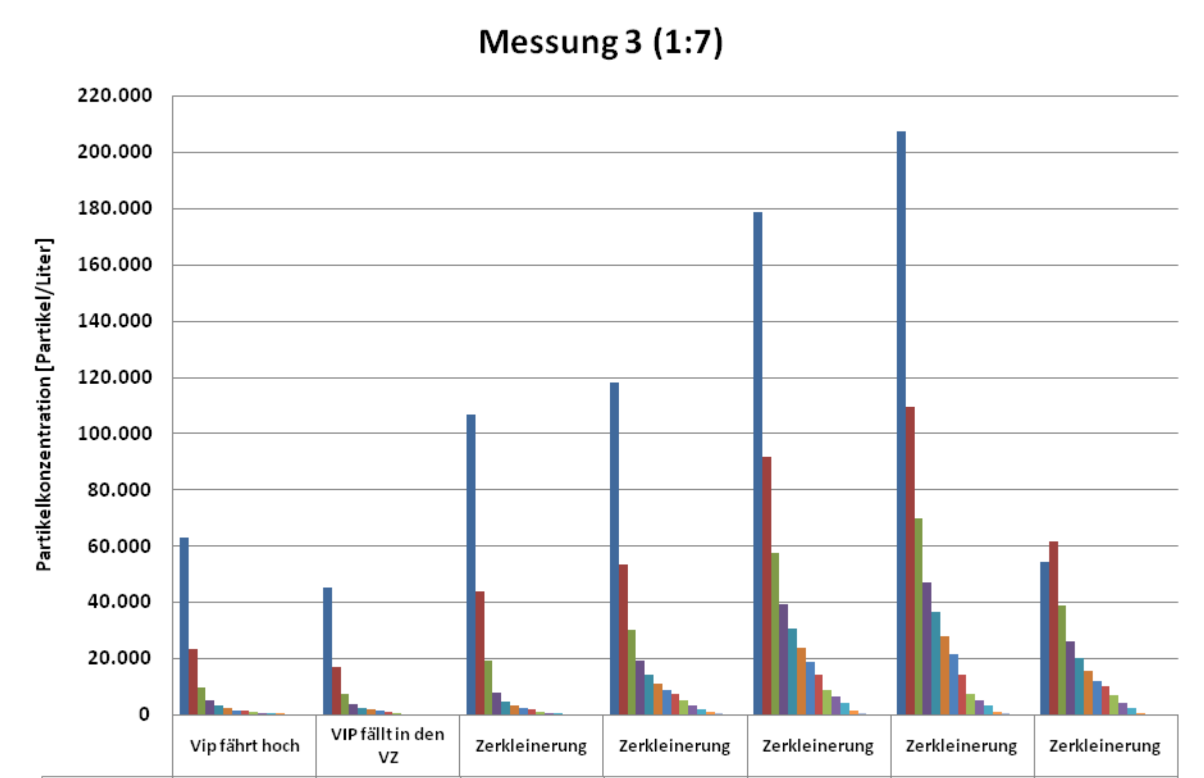


	Vip fährt hoch	VIP fällt in den VZ	Zerkleinerung	Zerkleinerung	Zerkleinerung	Zerkleinerung	Zerkleinerung	Zerkleinerung	Zerkleinerung	Zerkleinerung
0.30-0.40 µm	22908	22684	95913	101897	189888	119784	74902	68469	73405	57600
0.40-0.50 µm	8768	8220	41820	57572	117804	64940	34394	30167	41508	22480
0.50-0.65 µm	4260	4003	25478	38412	85116	43420	19773	16967	22186	11049
0.65-0.80 µm	2205	1992	16257	26646	62922	30648	12511	10387	12664	5754
0.80-1.0 µm	1402	1195	12270	21026	51555	24384	9380	7619	8851	3752
1.0-1.6 µm	986	812	9338	16601	41478	19096	7144	5655	6261	2580
1.6-2.0 µm	740	570	7186	13037	32851	14438	5333	4061	4396	1810
2.0-3.0 µm	560	423	4375	9365	27828	11780	4169	3266	3169	1415
3.0-4.0 µm	337	240	1935	5161	18269	7477	2332	1896	1617	775
4.0-5.0 µm	224	152	1340	3444	11837	4683	1407	1121	954	458
5.0-7.5 µm	127	92	809	2020	6709	2629	734	585	516	247
7.5-10.0 µm	32	36	243	639	1927	802	195	151	149	72
10.0-15.0 µm	8	20	92	242	670	313	62	49	52	25
15.0-20.0 µm	2	7	27	75	169	97	18	15	12	5
>20.0 µm	1	5	16	42	95	52	8	8	4	2

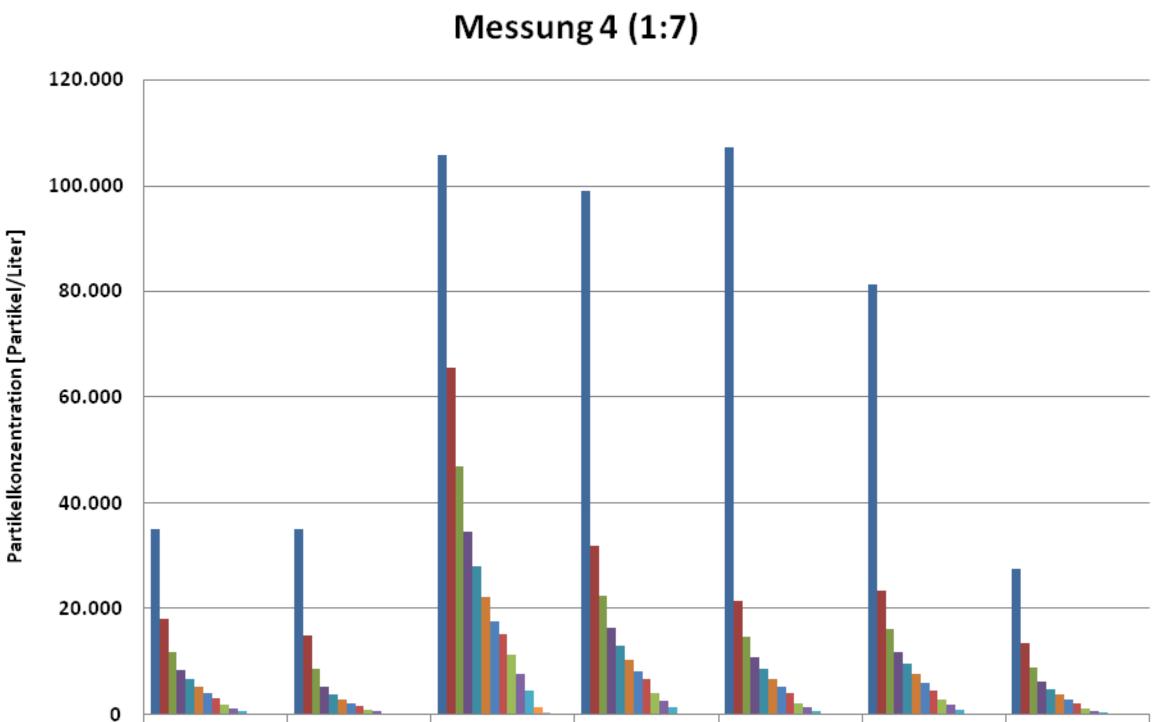
Taking into account the baseline measurement, both charts show that the size of the emissions and the decay curves follow similar curves. No significant increase in dust emissions can be detected between the first and last processing runs.

The following two charts show emissions when processing a combination of 1 VIP to 7 conventional appliances.

The first chart shows the emissions during the first processing run, the second one the last processing run with the combination ratio.



	Vip fährt hoch	VIP fällt in den VZ	Zerkleinerung	Zerkleinerung	Zerkleinerung	Zerkleinerung	Zerkleinerung
0.30-0.40 µm	63065	45110	106367	117974	178630	207153	54194
0.40-0.50 µm	23433	16718	43769	53152	91491	109159	61624
0.50-0.65 µm	9789	7295	19023	30115	57294	69805	38618
0.65-0.80 µm	4785	3723	7756	19014	39159	46992	25969
0.80-1.0 µm	3148	2477	4473	14290	30480	36576	20108
1.0-1.6 µm	2083	1724	2963	11083	23848	27957	15580
1.6-2.0 µm	1437	1241	2097	8664	18830	21412	12002
2.0-3.0 µm	1160	938	1637	7170	14037	14183	10070
3.0-4.0 µm	795	532	1024	4903	8858	7411	6687
4.0-5.0 µm	586	317	715	3371	6620	5234	4224
5.0-7.5 µm	435	168	424	2136	4379	3338	2313
7.5-10.0 µm	303	51	150	781	1458	978	605
10.0-15.0 µm	131	22	58	338	608	346	190
15.0-20.0 µm	22	7	17	112	191	84	40
>20.0 µm	5	4	8	59	95	38	21

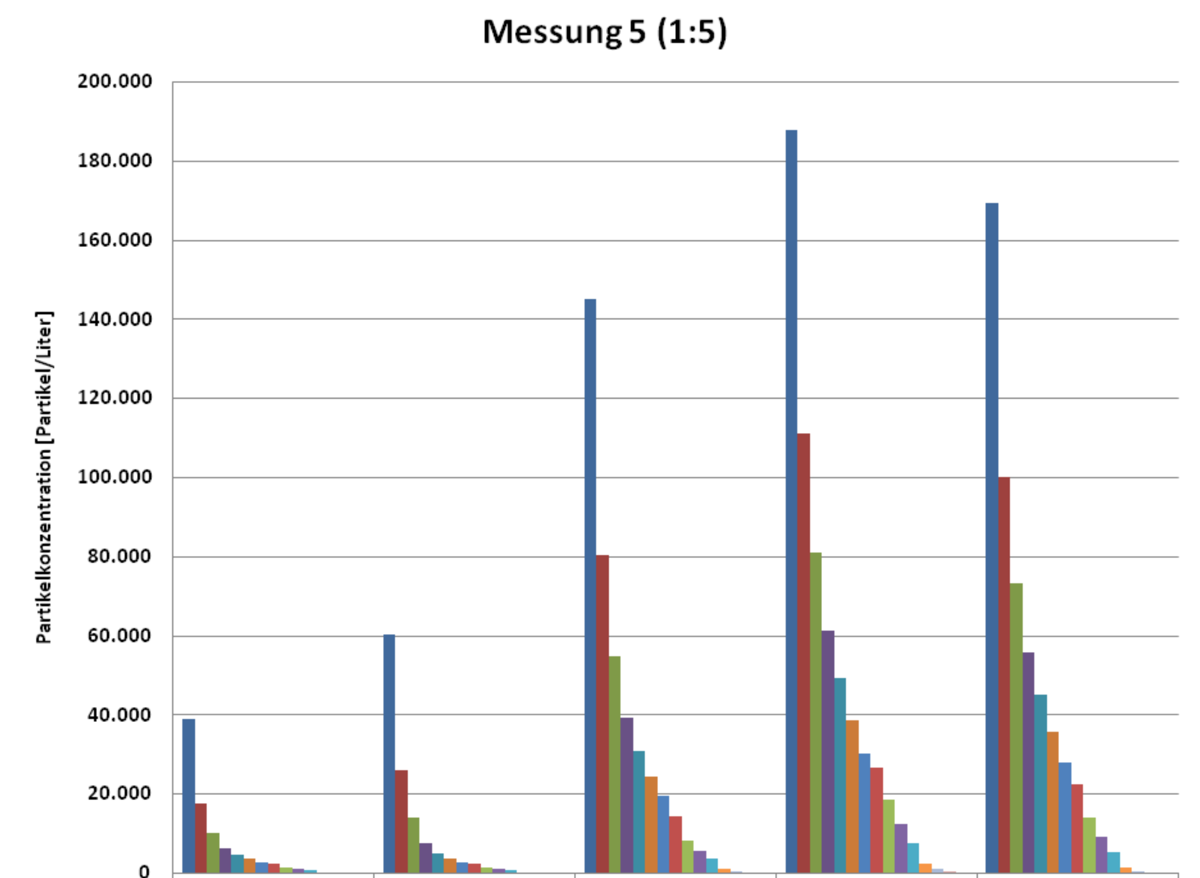


	Vip fährt hoch	VIP fällt in den VZ	Zerkleinerung	Zerkleinerung	Zerkleinerung	Zerkleinerung	Zerkleinerung
0.30-0.40 µm	35115	35016	105651	98919	107097	81212	27580
0.40-0.50 µm	18104	15019	65468	31982	21586	23477	13575
0.50-0.65 µm	11892	8653	46965	22422	14806	16193	8894
0.65-0.80 µm	8553	5414	34599	16527	10826	11946	6269
0.80-1.0 µm	6768	3972	28030	13170	8746	9608	4918
1.0-1.6 µm	5327	2966	22325	10402	6850	7652	3753
1.6-2.0 µm	4153	2179	17693	8121	5356	5967	2845
2.0-3.0 µm	3244	1734	15153	6680	4023	4712	2218
3.0-4.0 µm	1882	1010	11305	4169	2235	2986	1276
4.0-5.0 µm	1181	620	7654	2597	1369	1839	761
5.0-7.5 µm	629	318	4602	1429	748	1044	413
7.5-10.0 µm	182	81	1480	432	201	337	119
10.0-15.0 µm	79	30	582	153	66	145	45
15.0-20.0 µm	26	8	152	31	16	43	10
>20.0 µm	9	5	73	9	6	15	4

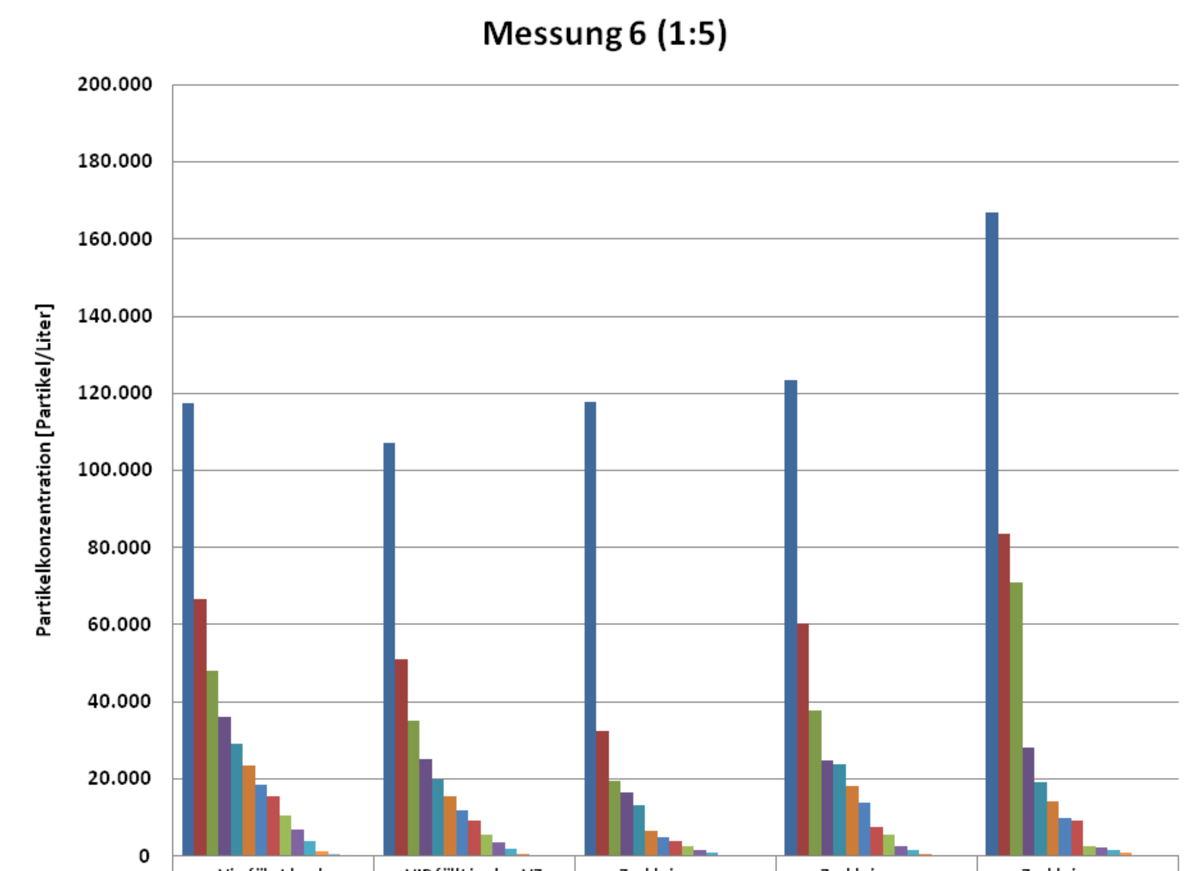
Taking into account the baseline measurement, these two charts also show that the size of the emissions and the decay curves follow similar curves. No significant increase in dust emissions can be detected between the first and last processing runs.

The following three charts show emissions when processing a combination of 1 VIP to 5 conventional appliances.

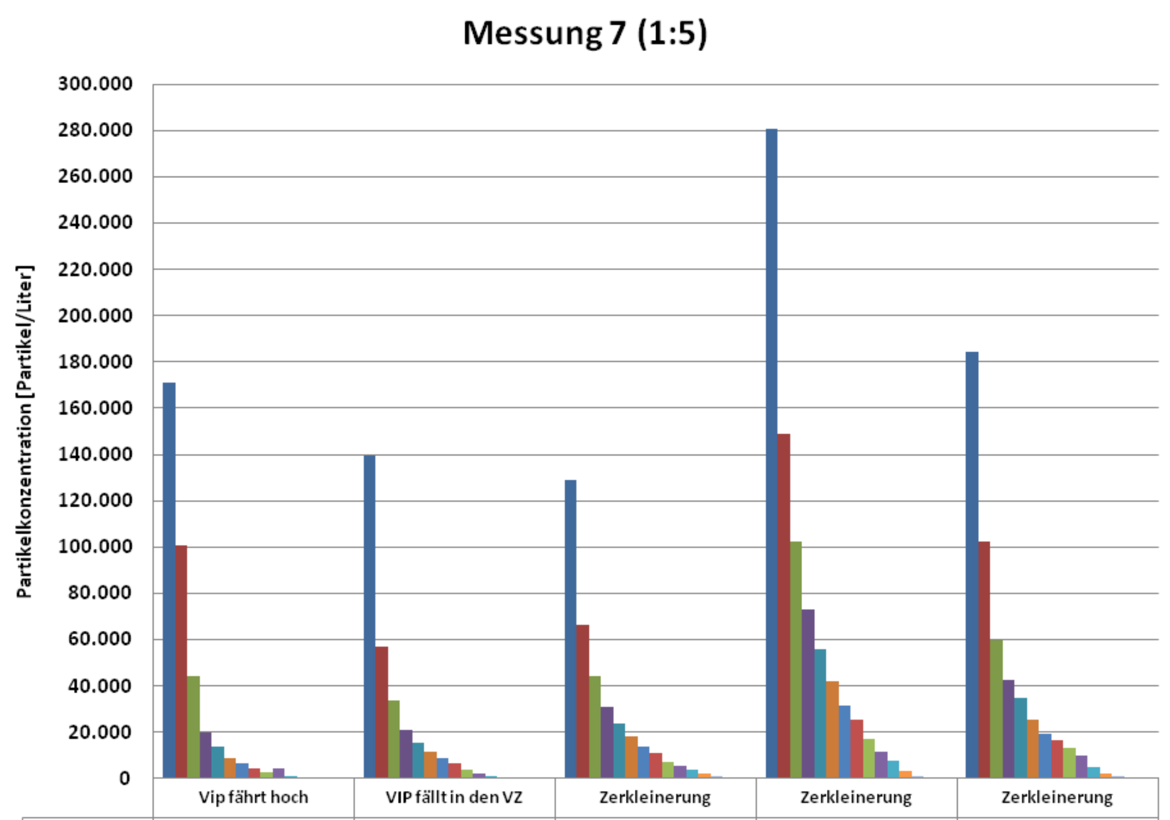
The first chart shows the emissions during the first processing run, the third one the last processing run with the combination ratio. The second chart shows the measurements recorded in between.



	Vip fährt hoch	VIP fällt in den VZ	Zerkleinerung	Zerkleinerung	Zerkleinerung
0.30-0.40 µm	38714	60339	144960	187651	169279
0.40-0.50 µm	17369	25843	80309	111018	99899
0.50-0.65 µm	9991	13756	54649	80962	73058
0.65-0.80 µm	6138	7374	39225	61305	55744
0.80-1.0 µm	4639	5000	30847	49206	44976
1.0-1.6 µm	3596	3557	24354	38494	35464
1.6-2.0 µm	2721	2573	19291	30210	27981
2.0-3.0 µm	2134	2151	14135	26692	22353
3.0-4.0 µm	1394	1432	8178	18347	14070
4.0-5.0 µm	936	954	5615	12146	9087
5.0-7.5 µm	516	593	3550	7329	5157
7.5-10.0 µm	142	203	1116	2406	1525
10.0-15.0 µm	42	87	404	873	498
15.0-20.0 µm	11	23	97	215	95
>20.0 µm	7	14	43	90	42



	Vip fährt hoch	VIP fällt in den VZ	Zerkleinerung	Zerkleinerung	Zerkleinerung
0.30-0.40 µm	117367	107233	117670	123387	166796
0.40-0.50 µm	66582	51164	32606	60450	83482
0.50-0.65 µm	47931	35246	19356	37900	70806
0.65-0.80 µm	36174	25217	16514	24811	28112
0.80-1.0 µm	29200	19939	13084	23714	19279
1.0-1.6 µm	23487	15577	6462	18191	14218
1.6-2.0 µm	18566	12034	4895	13990	9837
2.0-3.0 µm	15558	9152	3996	7532	9262
3.0-4.0 µm	10684	5525	2551	5546	2565
4.0-5.0 µm	7007	3571	1670	2725	2291
5.0-7.5 µm	4036	1971	969	1651	1736
7.5-10.0 µm	1237	552	320	622	1008
10.0-15.0 µm	451	191	132	294	358
15.0-20.0 µm	98	36	38	100	171
>20.0 µm	43	12	21	46	107



	Vip fährt hoch	VIP fällt in den VZ	Zerkleinerung	Zerkleinerung	Zerkleinerung
0.30-0.40 µm	171057	139335	129084	280364	184530
0.40-0.50 µm	100704	56904	66456	148735	102614
0.50-0.65 µm	44200	33503	44121	102291	60047
0.65-0.80 µm	20149	21304	31003	72839	42570
0.80-1.0 µm	14014	15771	23801	56116	34777
1.0-1.6 µm	8596	11664	18031	42233	25419
1.6-2.0 µm	6571	8600	13901	31566	19316
2.0-3.0 µm	4455	6578	10997	25555	16837
3.0-4.0 µm	2979	3725	7160	17148	13280
4.0-5.0 µm	4287	2384	5435	11856	9861
5.0-7.5 µm	880	1374	3959	7746	4725
7.5-10.0 µm	288	451	1969	2857	1899
10.0-15.0 µm	116	186	1044	1260	1120
15.0-20.0 µm	60	59	397	322	215
>20.0 µm	29	22	180	151	188

The charts clearly show a continuous increase in dust emissions as the processing run proceeds.
The emissions when non-VIP refrigeration units are processed no longer fall to the level of the first processed appliance, so that during subsequent processing, the emissions cumulate and continuously rise overall.

12 Material inspection after processing of Batch 2

Sample 5 after 30 refrigeration appliances (combination ratio 1:10). Sample taken at: screw conveyor after pre-shredder

Sample 6 after 30 refrigeration appliances (combination ratio 1:7). Sample taken at: pre-shredder

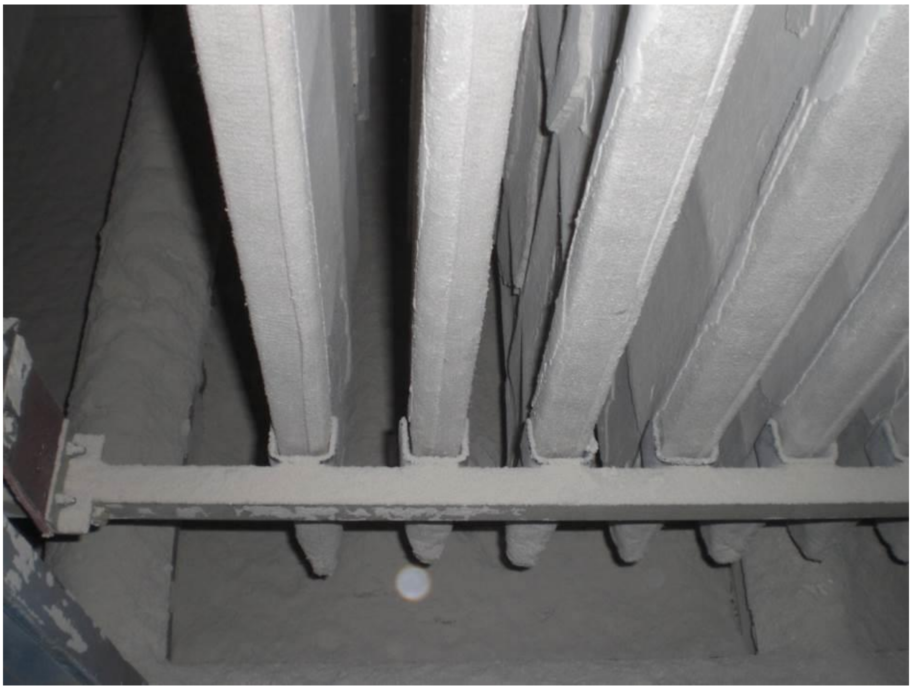
Sample 7 (combination ratio 1:5). Sample taken at: screw conveyor after pre-shredder

The material once again displays the original colour.

13 Inspection of filters on completion of processing

The plant's dust filters were inspected prior to the trials with Batch 1 and Batch 2.

Cartridge dust filter above the cross-stream shredder before processing.



Pocket filter before processing

Wet filter before processing

On completion of processing both batches, the filters were inspected again.

Cartridge dust filter above the cross-stream shredder after processing

No significant visual changes to the filter material were observed.

Pocket filter after processing

No significant visual changes to the filter material were observed.


Wet filter after processing

The filter inserts in the wet filter shows a clear dark colour.

Further checks as to which types of filters are able to retain the emitted particle sizes are required.

14 Trial results

Processing refrigeration appliances with VIP in today's recycling plants seems feasible, however, the plants should be modified accordingly. The modification will probably need to be designed and implemented individually depending on the technology in use.

The shredders seem to be fit for use without any further modifications.

Processing refrigeration appliances with VIP mainly presents challenges as to ensuring that the plant is leak tight. However, in terms of CFC and hydrocarbon emissions and workplace pollution, this topic already has the highest priority.

There is an increase risk of dust explosions in plants where the shredder room does not have an inerting system. This should be checked and taken into consideration where appropriate.

Filtering of process gas should be checked with regards to the filter’s capacity to separate the emitted particle sizes and modified where appropriate.

The trial processing runs also highlighted that the installed sensors and gas monitoring systems at the shredders need modification. Build-up on the measuring surfaces or blockages in the measuring gas lines must be avoided and checked appropriately

Inspection of the materials revealed that a proportion of the VIP dust is not removed via the extraction system, but sticks to the solid matters. The amount that sticks and for how long will likely vary from plant to plant, however, it is unlikely that this would negatively affect any commercialisation. Recycling foam insulation into an oil-binding agent could be an exception, however, further investigation is required.

The second day of processing revealed that when processing a combination of no more than one appliance with VIP to every seven processed appliances, no significant lasting increase of dust emissions occurred.

Duisburg, 27 November 2013

J. Schiemann, Dipl.-Ing.　　　　H.J. Prause, staatl. Gepr. Techniker

Uneditable text in images

Partikelkonzentation	Particle concentration
Partikel/Liter	Particle/litre
Partikelgröße	Particle size
Messung	Measurement
VIP fährt hoch	VIP goes up lift
VIP fällt in den VZ	VIP falls into the pre-shredder
Zerkleinerung	Shredding

[logo]
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Notice of delivery

Institut für Energie- und Umwelttechnik e.V.
IUTA
Bliersheimer Straβe 60
D-47229 Duisburg

File number
56.01.04-8850.1-IUTA
when answering, please refer to

Date: 11.08.2006

Application by IUTA dated 20 April 2006 to be approved to carry out tests in the meaning of the first general administration regulation of the Federal Immission Protection Law (Technical Instructions on Air Quality Control – TA Luft) of 24 July 2003 (Joint Ministerial Gazette, p 511) No. 5.4.8.10.3 and No. 5.4.8.11.3.

Notice of approval

Based on the application by Institut für Energie- und Umwelttechnik e.V. (IUTA) dated 20 April 2006, approval is hereby awarded to conduct tests in the meaning of TA Luft No. 5.4.8.10.3 and No. 5.4.8.11.3.

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300 500 00 West LB AG
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BIC: WELADEDD

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North Rhine-Westphalia
State Agency for Nature,
Environment and Consumer Protection

Notification

of test body status in accordance with
sec. 26 of the Federal Immission Protection Law (BImSchG).

I

IUTA
Institut für Energie- und Umwelttechnik e.V.
Bliersheimer Straβe 60
D-47229 Duisburg

is hereby notified as a test body for the state of North Rhine-Westphalia for the groups and areas set out in section II

Effective as of:15 September 2009
Expiry date: 15 September 2014

II

Scope of groups and areas

☒ **Group I:**

Determining emissions and/or immissions

Sections 26 and 28 of the Federal Immission Protection Law and corresponding measurement tasks according to regulations and the General Administration guidelines of the Federal Immission Protection Law (except for testing incineration conditions according to section 13, par. 1 of the 17th Federal Immission Protection Directive).

☐ **Group II** *(Group I is prerequisite)*

Testing appropriate installation and function as well as calibration of continually operating emission measurement equipment.

- N° 5.3.3 Technical Instructions on Air Quality Control Systems for the 4 Federal immission Protection Directives: Ordinance on installations subject to licensing, Annex column 2
- section 17a, par. 2 of the 1st Federal Immission Protection Directive
- section 12, par. 7 of the 2nd Federal Immission Protection Directive
- section 8, par. 4 of the 30th Federal Immission Protection Directive
- section 5, par. 4 of the 31st Federal Immission Protection Directive

[stamp: North Rhine-Westphalia State Agency for Nature, Environment and Consumer Protection]