Background Document
on the sector

Polystyrene processing

Prepared in the framework of EGTEI

Prepared by CITEPA, Paris

CONTENT

SNAP 06 03 03 or NFR 3C Chemical products manufacture and processing

Polystyrene can be transformed in several processes:

- Expanded polystyrene bead process: expanded polystyrene (EPS) moulding operation. The expandable polystyrene beads contain about 6 % in mass of pentane that acts as blowing agent during the process. Insulation panels and packages can be produced.
- Extruded polystyrene foam board process: polystyrene extrusion operation for obtaining regular small and uniform cell size. CO_2 can act as blowing agent as well as HCFC. Mainly insulation panels are produced.

In this document only the expanded polystyrene bead process is treated since the extruded polystyrene foam board process is less used and that NMVOC emissions are less important since CO_2 can be used.

Activity: Expandable polystyrene + recycled waste polystyrene (t/y)
Pollutants considered: NMVOC

1 Data currently used in the RAINS model

At its present stage of development, the RAINS sector PNIS (Products Not Incorporating Solvents) represents the polystyrene foam process together with polyester processing (snap 060301), polyvinyl chloride processing (snap 060302), polyurethane processing (snap 060303) and rubber processing (snap 060305). The activity level is directly represented by NMVOC emissions [4].

It is recognized in reference [4], that the PNIS sector includes a wide range of activity and that the definition of a typical and representative control option has been a difficult task. Assumption and simplification where made.

1.1 Control options

Three options of reduction are considered in the RAINS model as several combinations of these measures:

- Solvent management plans (SMP) : the use of lids on tanks, improvement of solvent delivery and handling systems is assumed to have an efficiency by up to 10%. The application potential ranges from 25 to 80% according to countries depending on the state of development and legal requirements.

- Add-on techniques (A-INC) : incineration or activated carbon adsorption are assumed to have applicability up to 70%.

- Substitution (SUB) : only viable for rubber processing. Applicability depends on the contribution of this industry to total emissions of the sector PNIS in a given country. Although efficiency can be as high as 100%, the overall applicability ranges from 5 to 10%.

1.2 Abatement measure costs

Table 1.2.1: Costs data used in the RAINS model [4] for France

	Emission factors kg NMVOC/kg NMVOC	Efficiency %	Technical efficiency %	Applicability %	Cost € 1990/t NMVOC
Activity level 1990 : 39.645 kt VOC emitted; 2010 : 46.741 kt VOC emitted, **VOC emission scenario business as usual :** 1990 : 39.65 kt VOC; 2010 : 34.71 kt VOC.					
No control	1.0000	0	0	0	0
SMP + SUB	0.9000	10	50	20	200
A_INC	0.5250	48	95	50	3 000
SMP+SUB+A_INC	0.4250	58	58	100	2 500

Table 1.2.2: Costs data used in the RAINS model [4] for Germany old Landers

	Emission factors kg NMVOC/kg NMVOC	Efficiency %	Technical efficiency %	Applicability %	Cost € 1990/t NMVOC
Activity level 1990 : 27.026 kt VOC emitted; 2010 : 30.631 kt VOC emitted. **VOC emission scenario business as usual :** 1990 : 27.03 kt VOC; 2010 : 21.59 kt VOC.					
No control	1.0000	0	0	0	0
SMP + SUB	0.9500	5	50	10	200
A_INC	0.43000	57	95	60	3 000
SMP+SUB+A_INC	0.3800	62	62	100	2 500

Table 1.2.3: Costs data used in the RAINS model [4] for Germany new Landers

	Emission factors kg NMVOC/kg NMVOC	Efficiency %	Technical efficiency %	Applicability %	Cost € 1990/t NMVOC
Activity level 1990 : 5.000 kt VOC emitted; 2010 : 5.667 kt VOC emitted. **VOC emission scenario business as usual :** 1990 : 5.00 kt VOC; 2010 : 4.96 kt VOC.					
No control	1.0000	0	0	0	0
SMP + SUB	0.9500	5	50	10	200
A_INC	0.43000	57	95	60	3 000
SMP+SUB+A_INC	0.3800	62	62	100	2 500

Table 1.2.4: Costs data used in the RAINS model [4] for Hungary

	Emission factors kg NMVOC/kg NMVOC	Efficiency %	Technical efficiency %	Applicability %	Cost € 1990/t NMVOC
Activity level 1990 : 0.013 kt VOC emitted; 2010 : 0.016 kt VOC emitted. **VOC emission scenario business as usual :** 1990 : 0.01 kt VOC; 2010 : 0.02 kt VOC.					
No control	1.0000	0	0	0	0
SMP + SUB	0.8500	15	50	30	200
A_INC	0.3350	67	95	70	3 000
SMP+SUB+A_INC	0.1850	82	82	100	2 500

Data are also available for other Parties. They can be downloaded from the IIASA's web site [5]. Investments and operating costs are not more detailed in the current documents and CITEPA cannot give more explanation on how costs have been derived.

EGTEI should at least provide more detailed data on rubber processing and on polystyrene foam processing.

2 Short technology description

Pentane impregnated polystyrene beads contain about 6% in mass of pentane. They are processed as follows [1]:

- Heating and stirring in an expander with steam. Pentane acts as a blowing agent which, when heated with steam, expands the beads. Additives such as antistatic and mould release agents are also added to the vessel.
- Drying in a fluidised bed: the resulting "pre-expanded beads" are transferred to a fluidised bed dryer where they are dried and screened to remove the agglomerated beads.
- Storage: dried pre-expanded beads are stored in large volume hanging cloths or mesh sacks for between some hours to several days according to the final product density to be obtained. During this curing time, air permeates into the beads and restores their internal pressure.
- Moulding: the cured pre-expanded beads are transferred into a mould where steam is admitted. The beads expand again but are constrained by the mould. They squeeze out all space and fuse to themselves to make an article of a shape determined by the mould.
- Storage of products. When insulation blocks are produced, the storage time depends again of the quality of insulation block to be obtained (density of these blocks).

When insulation boards are produced, EPS blocks are cut with electrically heated taut wires to the final dimensions desired.
According to products manufactured, one or two stages of pre-expansion and curing are required. Polystyrene wastes (polystyrene wastes from the production as recovered used polystyrene) can be recycled.

All NMVOC emissions result from the release of blowing agent (pentane) from the beads during processing, curing, moulding and storage.

The average emissions for each step of the process are presented in table 2.1 for the production of insulation boards.

Table 2.1 : NMVOC release proportion during the different process steps for the production of insulation boards.

Process step	Percentage of total NMVOC release
Pre-expansion	29 to 37%
Curing	5 to 20% according to the curing period
Moulding	4 to 6%
Residual pentane in product	40 to 55%

Emissions from the pre-expander can be collected. Emissions from the curing areas are not collectable. Pre-expanded beads are stored in very large volume rooms. The collection of air would result in very large flow rates and very low NMVOC concentrations.
Moulds are a difficult collection location because of the mould size, their number and their access requirements.
Total NMVOC emissions from the expandable polystyrene amount, on average, to 60 kg NMVOC/t expandable polystyrene processed when no recycled waste are used.

3 EU regulation

No EU regulation implementing VOC emission limits

4 Definition of reference installations

Only one reference installation is taken into account in this activity considering its low impact on total NMVOC emissions.

Table 4.1: Definition of reference installations

Reference Installation Code	Description
01	Medium Installation: annual polystyrene treated 3500 t / year

5 Emissions abatement techniques and costs

5.1 Definitions of primary measures

Expandable polystyrene beads with only 4% of pentane are presently available. However all product types cannot be produced with this 4% polystyrene. Low-density products that are the most produced (< 20-25 kg/m^3) cannot be obtained. In France for example, this limitation reduces the use of 4% expandable polystyrene to only 25% of the total production of expanded polystyrene.

Waste polystyrene recycling (Wastes from the site production as well as polystyrene wastes from outside recovery) is more and more frequently used. Wastes of expanded polystyrene are introduced during moulding. In Netherlands for example, the total volume of recycled polystyrene in the production units (waste can be recycled in other type of activities) is 5% [3]. The use of recycled polystyrene is however limited for quality reason. A level of 15% is taken into account in this document.

Table 5.1.1: Primary measures

Primary Measure Code	Description
00	Use of 100 % of 6 % pentane expandable beads
01	Use of 85 % of 6 % pentane expandable beads + 15 % of EPS wastes (recycling)
02	Use of 100 % of 4 % pentane expandable beads

5.2 Secondary measures

Activated carbon adsorption or incineration can be used to treat the pre-expander emissions. A gas collection system has to equip the pre-expander and the fluidised bed. For determining reduction costs, only thermal incineration technique has been considered (see the explanatory note).
An other reduction technique consists in ducting waste gases into a boiler. But costs of this technique have not been studied.

Table 5.2.1: Secondary measures

Secondary Measure Code	Description
00	No secondary measure
01	Thermal incineration on the expander

5.3 Emission factors, cost data and uncertainties of the different combinations

Table 5.3.1: Emission factors, abatement efficiencies and uncertainties for relevant combinations

Combination Code RIC PMC SMC	Emission factor for NMNMVOC [kg/t polystyrene[1]]	Abatement Efficiency [%]	Q	CI [%]
01 00 00	60	0	5	5
01 00 01	39.4	34.3	5	10
01 01 00	51	15	5	5
01 01 01	33.5	44.2	5	10
01 02 00	40	33.3	5	5

polystyrene[1] : new expandable beads + recycled polystyrene

Table 5.3.2: Investments, operating costs, uncertainties for relevant combinations

Combination Code	Investments [€]	Uncertainties %	Fixed Operating Costs [€/y]	Variable Operating Costs [€/y]	CI [%]
01 00 00	0				
01 00 01	248 650	30	12 430	14 340	25
01 01 00	0				
01 01 01	248 650	30	12 430	12 200	25
01 02 00	NA		NA	NA	

NA: not available.

6 Data to be provided by national experts for the completion of the data basis for their country

The following tasks are required:

6.1 Validation work

The national expert is invited to comment the methodology defined by the secretariat.

- Validation of the default investments provided,
- Validation of the method of derivation of operating costs,

Or

- Provide other costs for the same combination of techniques and justify them.

6.2 Provision of specific data

Tables to be filled in by national experts

- Determination of country specific data to calculate variable costs (Specific values for energy, man power… are valid for all VOC sectors and have to be entered in the tool only once)

Table 6.2.1: Country specific data

Parameters	Default value used	Country specific costs
Electricity [€/kWh]	0.0686	
Natural gas [€//kWh]	0.0192	
Wages [€/h]	25.9	

- Total activity level in t/y of EPS processed (New expandable polystyrene + waste polystyrene recycled).

Table 6.2.2 : Activity levels on reference installations (t/y new EPS processed + Recycled polystyrene)

RIC	2000	CI%	2005	CI%	2010	CI%	2015	CI%	2020	CI%
01										
Default values proposed for CI		10		20		50		100		100

- Respective percentage of combinations of reduction measures in 2000 as well as if possible, the percentage of use in 2005, 2010, 2015, 2020 due to national regulations and applicability factor according to the definition used in the RAINS model (refer to the methodology for explanation on Applicability factor).

Table 6.2.3 : Application rate and applicability factor for each combination of reduction measures

RIC PMC SMC	Application rate in 2000	Application rate in 2005	Appl. [%]	Application rate in 2010	Appl. [%]	Application rate in 2015	Appl. [%]	Application rate in 2020	Appl. [%]
01 00 00									
Proposal of the secretariat for applicability (1)			100		100		100		100
01 00 01									
Proposal of the secretariat for applicability (1)			100		100		100		100
01 01 00									
Proposal of the secretariat for applicability (1)			100		100		100		100
01 01 01									
Proposal of the secretariat for applicability (1)			100		100		100		100
01 02 00									
Proposal of the secretariat for applicability (1)			25		25		25		25
Total RIC 01		100		100		100		100	

(1) The applicability depends on the regulation of the country. In some countries, due to regulation PMC 00 could be forbidden. In that case, the rate of applicability is 0%.

In the tool the absolute terms are directly entered (% in a given combination multiplied by the total activity)

7 Explanatory notes

7.1 Reference installations

Reduction costs are only presented for an average reference installation of 3500 t/y in table 5.3.1. However to derive these costs, two cases have been taken into account.

Cases	Description
A	3300 t/y polystyrene processed
B	3700 t/y polystyrene processed

7.2 Derivation of Emission Factors

For primary measures, emission factors result directly from the definitions since all pentane can be assumed to be released sooner or later into the atmosphere (when insulation block are produced, 40 to 55 % of the initial pentane contained in EPS beads stay in the final product and is progressively released into the atmosphere inside the plant or outside. In order to avoid double counting, the residual pentane content of polystyrene waste (about 0.6 % representing 10 % of the initial pentane content of new beads) is not added.

Table 7.2.1: Emission factors for primary measures

Primary Measure Code	Description	Emission Factors [kg NMVOC/t polystyrene]
00	Use of 100 % of 6 % pentane expandable beads	60
01	Use of 85 % of 6 % pentane content expandable beads + 15 % of recycled EPS wastes	51
02	Use of 100 % of 4 % pentane content expandable beads	40

An incinerator can be used to treat the pre-expander and fluidised bed emissions. According to the own expertise of the author on this sector, it can be considered that 35 % of total emissions occur at these process stages and can be reduced after collection of waste gases. An efficiency of 98 % is taken into account for incinerator.

Table 7.2.2: Emission factors for secondary measure 01

Secondary Measure Code	Description	Efficiency
00	No controls	
01	Thermal incinerator (efficiency 98%) to treat the expander emissions or 35 % of total installation emissions treated	34.3 %

7.3 Derivation of Cost Data

Primary Measures

Primary measure 01:
No additional cost compared with new EPS beads is taken into account (Moreover, polystyrene wastes are probably cheaper than new EPS beads. But no data is available on recycling benefits).

Primary measure 02:
4 % pentane polystyrene beads require changes in production equipment: dis-continuous expanders must replace continuous expanders. Production cycles are completely modified and production times increase. No cost data is available.

Table 7.3.1: Emission factors, investments, operating costs, abatement efficiencies, technical lifetimes for relevant combinations of reference installations and primary measures.

Combina-tion Code	Emission Factor for NMVOC [kg/t polystyrene]	Abate-ment efficiency [%]	Invest-ment [€]	Operating Costs [€/a]	Tech. Life-time [a]	Abatement cost € / t NMVOC abated	CI %
Small Reference Installation							
A 00 00	60	0	0	0		0	5
A 01 00	51	15	0	0		0	5
A 02 00	40	33.3	NA	NA	20	NA	5
B 00 00	60	0	0	0		0	5
B 01 00	51	15	0	0		0	5
B 02 00	40	33.3	NA	NA	20	NA	5

NA: not available

Secondary Measures

Table 7.3.2 presents parameters used for estimating incinerator costs

Table 7.3.2: Characteristic parameters of installations.

Parameter	**Installation A**		**Installation B**	
Primary measures	00	01	00	01
Annual polystyrene processed: t new EPS treated t recycled polystyrene	3300	2805 495	3700	3145 555
Characteristic of the production chain Number of expanders	4 of small capacity expanders (400 kg/h/expander)		1 of large capacity expander (1200 kg/h)	
Working hours of expanders – h/a	5640	4800	4230	3600
Maximum expander NMVOC emissions – kg NMVOC/h (depending on the expander capacity)	33.6		25.2	
Average NMVOC flow rate – kg NMVOC/h	12.4		18.4	
Maximum flow rate – n m^3/h	3000		2300	
Average flow rate – n m^3/h	1100		1700	

Pentane characteristics:
Low calorific value: 44,7 MJ / kg
Auto ignition temperature: 260 °C
25 % of the Low Explosive limit: 11,3 g / n m^3

Waste gases have to be collected. Concentrations in waste gases can be high since the flow rate can be adapted. They are maintained to 25 % of the inferior limit of explosivity and waste gas flow rates are consequently variable. Due to variable flow rates, regenerative incinerator is less adapted than thermal incinerator. Due to pentane auto-ignition temperature, the primary thermal incinerator energy recovery efficiency is limited to 30 %.

Table 7.3.3: Emission factors, investments, operating costs for secondary measure 01 on installation A and B

Installation	A	A	B	B
Primary measures	00	01	00	01
Temperature	20	20	20	20
Emissions without incineration - t/y	198.0	168.3	222.0	188.7
Emissions with incineration - t/y	130.1	110.6	145.9	124.0
Emission factors with incineration – kg NMVOC/t polystyrene (new + recycled)	39.4	33.5	39.4	33.5
Efficiency of SMC 01 - %	34.3	34.3	34.3	34.3
Efficiency of the combination PM+SM compared to the combination PMC 00 and SMC 00	34.3	44.2	34.3	44.2
Investment - €	266 807	266 807	230 489	230 489
Annualised cost - €/y	32 895	32 895	28 417	28 417
Fixed operating cost - €/y	13 340	13 340	11 524	11 524
Electricity - €/y	213	181	247	210
Natural Gas - €/y	5 670	4 825	6 572	5 593
Man power - €/y	9 130	7 770	6 847	5 828
Total variable costs - €/y	15 012	12 776	13 666	11 630
NMVOC non emitted - kg/y	67 914	57 727	76 146	64 724
Total annual cost - €/kg COV	0.902	1.022	0.704	0.797

Installation A and installation B only differ on their production equipment characteristics. Installation A is equipped with 4 expanders of little capacity. Installation B is equipped with a large capacity expander.

In order to take these differences into account, the installation RIC 01 is considered to be an average installation between installation A and installation B.

Average costs for installation RIC 01 are presented in table 7.3.4.

Table 7.3.4: Emission factors, investments, operating costs for secondary measure 01 for reference installation 01 with PMC 00 or 01

Installation	RIC 01	RIC 01
Primary measures	00	01
Secondary measures	01	01
Emissions without incineration – t/y	210.0	178.5
Emissions with incineration - t/y	138.0	117.3
Emission factors with incineration – kg NMVOC/t polystyrne (new + recycled)	39.4	33.5
Efficiency of the combination PM+SM compared to the combination PMC 00 and SMC 00	34.3	44.2
Investment - €	248650	248650
Annualised cost - €/y	30660	30660
Fixed operating cost - €/y	12430	12430
Electricity - €/y	230	200
Natural Gas - €/y	6120	5210
Man power - €/y	7990	6800
Total variable costs - €/y	14340	12200
NMVOC non emitted – kg/y	72030	61230
Total annual cost - €/kg COV	0,803	0,910

8 Comments made by experts and changes made on the document

No comments have been received from national experts. This document has been checked by a French expert from this industry [6]. Some minor modifications have been done in order to give better explanations when necessary. The document has been distributed to the French and the European associations of PSE manufacturers [7] and [8]. Additional data on the costs of primary measure 02 are expected but this data has not been provided for the time being. The document will be completed if the information is given.

Following some lecture and use of the background document some minor mistakes have been identified and corrected.
Level of activity is better represented by using polystyrene instead of PSE due to some difficulties of understanding. The units have been corrected when necessary.
Default cost of electricity is 0.0686 €/kW instead of 0.0692
The unit costs presented in table 7.3.3 and 7.3.4 have been corrected.
The coma have been replaced by point to represent decimals in international way.

9 References

[1] CCME
Environmental guidelines for the reduction of NMVOC from the plastic processing industry
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[4] KLIMONT Z. ; AMANN M. ; COFALA J. :
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