# Costs related to specific waste streams for a WTE facility

**Bert Rijpkema**, Jan Zeevalkink
TNO Institute of Environmental Sciences, Energy Research and Process Innovation
Laan van Westenenk 501, 7334 DT AH Apeldoorn, The Netherlands
E-mail: Bert.Rijpkema@mep.tno.nl

## ABSTRACT

Because of the optimization of waste management structures WTE (Waste-to-Energy) facilities are frequently confronted with specific waste streams which are delivered to the facility for processing. Though it is generally realized that waste characteristics highly influence the performance of a WTE facility, in general, an average processing rate ('gate fee') per ton of waste offered is imposed, regardless the composition of the waste. This leads to an increasing need for an objective rating method for various individual waste materials, which also accounts for plant specific factors.

In this paper a methodology to calculate the specific processing cost of waste materials in a WTE facility is presented. This methodology is based on the use of the MSWC FACE-model, a computer programme which calculates the impact of a change in waste characteristics or process conditions on the emissions, residues, energy recovery and costs of a WTE facility. The methodology results in a processing cost classification of specific waste materials offered to a WTE facility for processing, which can be applied to almost any WTE facility.

## INTRODUCTION

Optimization of waste management structures is an important issue in the environmental policy of the Netherlands as well as many other countries. This optimization may be acquired by using an integrated approach for the disposal of waste streams. After prevention, re-use and recycling, combustion with energy recovery is considered preferable to landfill, sometimes backed up by governmental policy measures as for example the ban on landfilling combustible wastes in the Netherlands.

Prevention and recycling efforts will a priori not provide complete solutions: for many waste streams combustion is a necessary and unavoidable part of the total waste disposal structure. Within this scope WTE (Waste-to-Energy) facilities are frequently confronted with specific waste streams which are delivered to the facility for processing. Therefore, there is a need for improved understanding of the environmental effects and cost which result from the combustion of these specific waste streams in WTE facilities. Such understanding is important in decision making to optimize various final processing routes.

In general, an average processing rate ('gate fee') per ton of waste offered is imposed, regardless the composition of the waste. There is, however, an increasing need for an objective rating method for various individual waste materials, as it is realized that different types of materials have different impacts on the performance and cost of such a facility, which also accounts for plant specific factors. The Ministry of Housing, Spatial Planning and Environment (VROM) and the Association of Plastics Manufacturers in Europe (APME) jointly assigned TNO to develop such a methodology.

## OBJECTIVES

The objectives of the study were:

- to develop a methodology in which the different properties of various types of waste materials are reflected in their specific processing costs (SPC's) in an existing WTE facility;
- to apply this methodology to calculate the specific combustion costs of specific waste materials like (mixed) plastics, PVC, putrescibles, glass, wood, metals and paper.

## DESCRIPTION OF THE METHODOLOGY

The developed methodology uses an existing computer model (the MSWC FACE-model: Municipal Solid Waste Combustion Flow And Cost Expert model). With the configuration of the Alkmaar WTE facility (which can be looked upon as a typical modern Dutch WTE facility; see Appendix A), the waste composition and the process conditions as input, this model calculates:

- mass and energy flows of the WTE facility;
- fixed and variable costs of processing MSW in the WTE facility.

The MSWC FACE model enables the investigation of mass, energy and financial effects caused by the addition of a specific waste material to a WTE facility, in which a well-defined reference household waste ("grey waste") is combusted. For the calculation of the processing costs of this specific waste material, it is stated that the calculated change in total annual costs must be compensated by the specific processing cost of the added waste material (break-even). The calculations are based on the elementary compositions of the waste materials as only inputs, regardless their physical characteristics.

A mathematical relationship has been developed to relate the results of these calculations to the specific processing costs of the waste material under consideration. Fixed and variable costs per tonne can be calculated for each waste material. The revenues of the energy production are included in the net variable costs. Cost calculations have been conducted from the operator's point of view.

In a fully loaded plant, acceptance of each tonne of an alternative waste material (at a processing fee) will displace a certain amount of the WTE facility's normal "grey" waste. The processing revenues from the displaced grey waste are forfeited; alternatively, the internal processing costs are avoided (see Appendix B). Three scenarios have been considered, each describing a theoretical extreme in WTE facility operation in terms of throughput capacity:

- *Thermal limitation*. The throughput of the WTE facility is limited by the heating value of the waste feed. Addition of the specific waste displaces a quantity of reference grey waste proportionally to the heating value ratio between added waste material and grey waste. The calculated specific processing costs for the added material account for the variable costs of this waste as well as the specific fixed costs, where the latter is proportional to the heating value ratio.
- *Mass limitation*. The WTE facility throughput is limited by mass. The addition of one tonne of added waste substitutes one tonne of grey waste. The calculated specific processing costs account for the variable costs of the added waste material and a share in the fixed costs identical to the original share of the displaced grey waste.
- *No throughput limitation*. The calculated specific processing costs only reflect variable costs.

In the Netherlands, individual WTE facilities are generally thermally limited, whereas gate fees are charged on a mass basis. The scenario without throughput limitation is only incidentally encountered in real-life WTE facilities, as obviously it reflects an economically unstable situation.

As an example, the process conditions and cost data (design situation) of a modern (Dutch) WTE facility, the HVC Noord-Holland at Alkmaar, have been used to tune the MSWC FACE-model. This plant is provided with a spray-dryer for evaporation of purified scrubber effluent. The residues are then landfilled. Alternatively, a configuration with discharge of purified scrubber effluent has been used for calculation as it was anticipated that some waste materials would be affected by this difference in scrubber effluent treatment (see Appendix A).
Figure 1 and 2 show the resulting specific processing costs. In the 'no limitation' scenario, these cost data coincide with the variable costs of processing a specific waste material. In the other cases, the data include both fixed and variable costs.
In these calculations, soft and rigid PVC need to be distinguished. Soft PVC contains relatively high amounts of plasticizers compared to rigid varieties. As a result, soft PVC is lower in chlorine-content and higher in heating value. As these two parameters are expected to have a substantial impact on the specific processing costs, these two types of PVC have been treated separately in the study.

## RESULTS OF THE SPECIFIC PROCESSING COSTS CALCULATIONS

Specific processing costs have been calculated for soft and rigid PVC, (mixed) plastics (including PVC), wood, putrescibles, paper, glass and metals (see figures 1 and 2).
The calorific content of the waste materials in relation to the grey waste reference is dominating the results in many cases: metals, glass, putrescibles have heating values below the grey reference, paper and grey waste have about identical heating value, whereas wood, any type of PVC and all other plastics have a higher energy content.
In case the WTE facility is considered thermally limited, high calorific waste materials show relatively high SPC's; wastes with a relatively low heating value incur lower costs.
In case the WTE facility is considered mass limited, low calorific waste materials show relatively high SPC's. Wastes with a high heating value benefit from their contribution to the energy proceeds and incur lower costs in this case.
In the absence of throughput limitation when only variable costs determine break-even, waste materials have specific processing costs that are obviously well below the gate fee for original grey waste and in most cases even are negative. Glass, metals and in some cases PVC are exceptions, as residue disposal costs have a large impact and glass and metals have zero energy content and, as a consequence, do not generate electricity revenues.

The main distinction in specific processing costs between PVC and other waste materials are its variable costs, resulting from required chloride removal from the flue gases. At WTE facilities where salt containing effluent from the wet scrubber (after purification) cannot be discharged, this effluent must be evaporated and the resulting solid salt residue deposited in a landfill.
These additional variable costs, which are mainly determined by salt disposal, are significantly higher for rigid than for soft PVC. The latter has a lower chloride content (and consequently lower chloride removal and disposal costs) and generates higher energy recovery revenues. In the case where the purified scrubber effluent is discharged, the additional variable costs for PVC are considerably (70%) lower. Despite the additional variable costs, which add significantly to the specific processing costs of PVC, the SPC of plastics in a thermally limited WTE facility is higher than for PVC. This is due to

the large demand on thermal capacity claimed by plastics, which have the highest calorific value of the materials considered in this study.

## IMPLICATION OF THE RESULTS

*To which WTE facilities do the results apply ?*

In principle, the developed methodology applies to any facility (with a grate furnace), regardless its configuration and cost structure (investments, disposal costs, energy revenues, etc.).

*Under which conditions do the results apply ?*

The quantitative results, obtained by this methodology, are dependent on the local situation of the WTE facility. Prior to calculations, the model must be tuned by feeding it with specific data of the facility, as considered.

As the model has been validated for actual practice, the calculated costs are directly related to this situation. The results are valid as long as the facility is operated within its regular window of operation. This implies that the calculated specific processing costs only apply if relatively limited amounts of waste are added (incremental approach).

Furthermore the method has not been developed to determine the processing costs of the waste materials which are already part of the "grey" reference waste.

*To what extent can the results be extrapolated?*

Calculated costs are valid for the HVC Noord-Holland (and its alternative with discharge of scrubber effluent) and are only indicative for facilities in general.

More exact results for other WTE facilities depend on configuration, specific cost structure and plant loading nation-wide. Extrapolation of the results to a complete country is not directly possible.

*To what extent are the results dependent on the amount of putrescibles (kitchen and yard waste) in the total grey waste ?*

The effect of a decrease in the amount of putrescibles in grey waste (as in waste arising predictions by the Dutch Waste Management Council) was studied. The specific processing costs for any specific waste material are independent of such a change. However, the processing costs of the "grey" waste increase for a thermally limited WTE facility. Due to an increase in the calorific value of the "grey" waste fewer tonnes can be processed which results in a larger share of the fixed costs per tonne of "grey" waste.

## CONCLUSION

The study describes a methodology for calculation of the specific processing costs for all kinds of waste materials for a given WTE facility at a given type of plant loading. This methodology can be applied to any plant configuration, once specific process conditions and cost factors have been introduced. The methodology can generate useful information to Governments as well as Industry as an input for deciding between waste management options for specific waste types like e.g. hazardous waste, shredder waste or consumer electronics waste. Furthermore, the specific environmental impacts of combustion of plastics, paper, putrescibles etc. relative to "grey" waste can be determined.

**Figure 1.** Specific processing costs for a WTE facility with <u>evaporation</u> of the purified scrubber effluent.

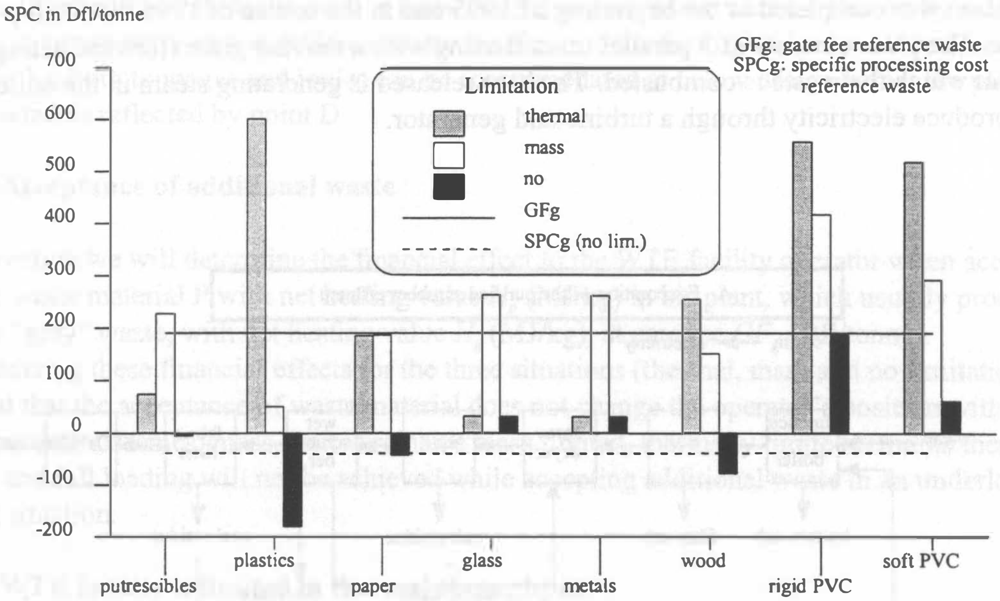
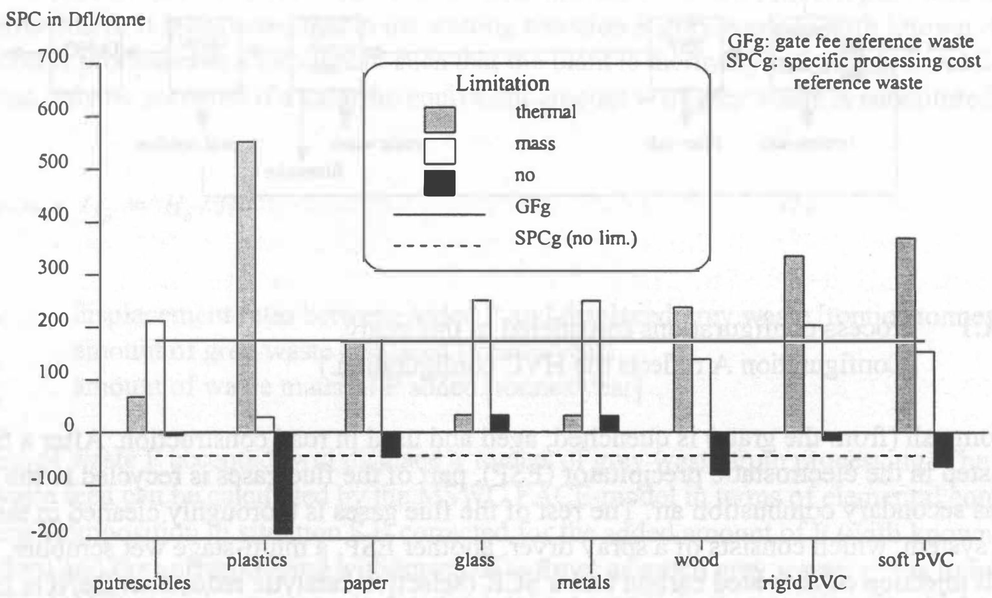



**Figure 2.** Specific processing costs for a WTE facility with <u>discharge</u> of the purified scrubber effluent.



## APPENDIX A THE HVC NOORD-HOLLAND

The Huisvuilcentrale (HVC) Noord-Holland is a completely new installation, built at a green site. Construction was completed at the beginning of 1995 and in the course of 1995 the facility went into operation. The plant consists of 3 parallel units starting with a moving grate (forward acting type) furnace, in which the waste is combusted. The heat released is generating steam in the boiler which is used to produce electricity through a turbine and generator.

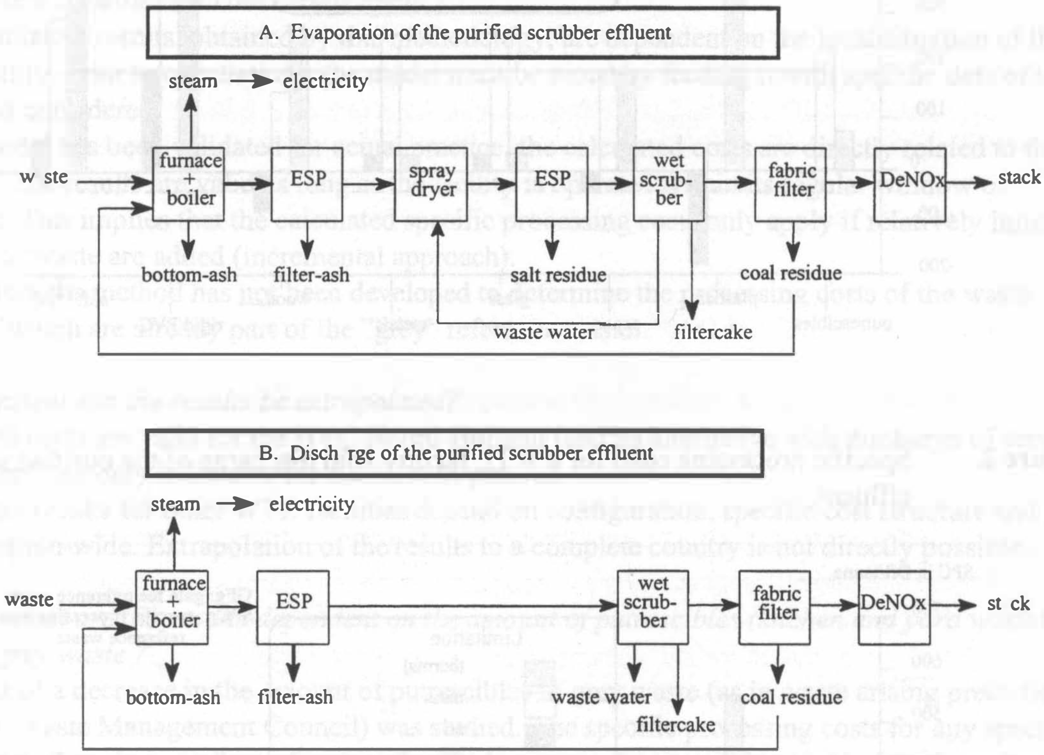



**Figure A.1** Process configurations considered in this study. (Configuration A reflects the HVC configuration.)

The bottom-ash (from the grate) is quenched, aged and used in road construction. After a first dust removal step in the electrostatic precipitator (ESP), part of the flue gases is recycled to the furnace to be used as secondary combustion air. The rest of the flue gases is thoroughly cleaned in the flue gas cleaning system, which consists of a spray dryer, another ESP, a multi-stage wet scrubber, a fabric filter with injection of activated carbon and a SCR (selective catalytic reduction) DeNOx installation. The scrubber effluent is purified (neutralization, flocculation, precipitation and filtration) and evaporated in the spray dryer. The fly-ash, which is separated from the flue gas in the ESP, is used as filling material in road construction.
The residue from the second ESP after the spray dryer is collected and landfilled in big bags at a controlled landfill site. This residue is mainly calciumchloride with some impurities (dust, residual heavy metals) which were adsorbed/captured by the salt particles in the spray dryer. Due to the temperature at which the scrubber effluent is evaporated in the spray dryer, no crystal water is

decreased: the plant is heat limited in processing waste, reflected by point B.
If waste with a calorific content below design value is combusted, throughput could be increased to arrive at the original thermal loading. However, the hroughput is limited to the original mass throughput based on design: the plant is mass limited in processing waste, reflected by point C.
Finally, in situations where insufficient waste is offered to the facility and amounts and heating value are such that both tonnages and joules can be accommodated at below design value: the plant is underloaded as reflected by point D.

## B.2 Acceptance of additional waste

In this section we will determine the financial effect to the WTE facility operator when accepting specific waste material P with net heating value $H_p$ (MJ/kg) in his plant, which usually processes average "grey" waste, with net heating value $H_g$ (MJ/kg), at gate fee $GF_g$ (Dfl/tonne).
In considering these financial effects for the three situations (thermal, mass and no limitation), it is assumed that the acceptance of waste material does not change the operator's position with respect to the theoretical extremes: mass limited remains mass limited, thermally limited remains thermally limited and full loading will not be achieved while accepting additional waste in an underloaded starting situation.

### a. WTE facility is limited in thermal throughput

Thermal limitation is generally incurred in the boiler in which the heat exchanging surface limits the amount of heat which can be transferred from the hot flue gases for steam generation.
In practice, many WTE facilities may be thermally limited as the average heating value of the grey waste has increased continuously during the last decades (by an increase of high calorific materials like plastic and paper and/or a decrease of low calorific materials like putrescibles).
The MSWC FACE-model is able to calculate the total net annual cost $F_s$ (in Dfl per year) in the starting situation S. It is assumed that in the starting situation S grey waste G with known elemental composition is processed at a throughout such that the plant is thermally fully loaded. Additional waste P can only be accepted if a calorific equivalent amount $w$ of grey waste is substituted: this means

$$w = t_g / t_p = H_p / H_g \qquad (1)$$

where:

- $w$ displacement ratio between added P and displaced grey waste [tonnes/tonnes]
- $t_g$ amount of grey waste displaced [tonnes/year]
- $t_p$ amount of waste material P added [tonnes/year]

Each tonne of waste P accepted, will displace $w$ tonnes of grey waste from processing. The new WTE facility waste feed can be calculated by the MSWC FACE-model in terms of elemental composition. The original composition in situation S is corrected for the added amount of P (with known elemental composition) and the corresponding withdrawal of $w$ times as much grey waste: $t_p * w$ tonnes per year. The MSWC FACE-model can now calculate the total net cost $F_n$ in the new situation N, based on the adjusted elemental composition. The calculated financial effect on the cost to the WTE facility operator is $F_n - F_s$ (which can be either positive or negative).
In order to achieve financial break-even these (increased or reduced) costs should be compensated in the operator's income. This compensation is represented as $t_p * SPC_p$, or the amount of P added ($t_p$ tonnes/year) times the specific processing cost of P ($SPC_p$ Dfl/tonne).

However, the fee for processing the displaced amount of grey waste ($t_p * w$ tonnes/year) has been forfeited: $t_p * w * GF_g$.
Therefore:

*cost difference = revenu difference*

*cost (new) - cost (old) = extra revenue - missed revenu*

$$F_n - F_s = t_p * SPC_p - t_p * w * GF_g \quad (2)$$

Now, $SPC_p$ (the cost to be charged per tonne of P processed to maintain financial break even) can be calculated:

$$SPC_p = (F_n - F_s)/t_p + w * GF_g \quad (3)$$

$F_n$ and $F_s$ (total annual cost before and after waste addition in Dfl per year) are obtained from the MSWC FACE-model calculation, $w$ is derived from basic feed data and $GF_g$ is a contractual or commercial reality.

**b. WTE facility is limited in mass throughput**

At mass limitation, $t_p$ tonnes of additional waste P can be accepted only, when an equal mass $t_g$ of grey waste is displaced, i.e. $t_p = t_g$. For the substitution factor $w$ we can now write:

$$w = t_g / t_p = 1 \quad (4)$$

Reasoning analogous to the thermally limited situation, as described under a., provides a result identical to formula (3), where $w$ now equals 1 and is determined by mass rather than heating value.

**c. WTE facility is operating below capacity**

Situations without throughput limitations only occur in the situation where insufficient waste is offered to the plant to obtain full loading. As mentioned before, this situation is very unlikely to occur other than temporarily, like in early phases of the plant project life time, where temporarily overcapacity has been planned. However, from a theoretical point of view, this scenario is interesting as it provides the link to specific variable costs.
The plant operates below maximum throughput in terms of heat, mass or any other limiting factor. Acceptance of $t_p$ tonnes of waste invariably generates additional income, without missing revenues as no grey waste has to be displaced. From a financial point of view, the WTE facility operator can accept additional waste as long as the cost difference $F_n - F_s$ is covered, as can be seen from formula (3). As no grey waste is displaced, the substitution factor $w$ equals 0, eliminating the original gate fee for grey waste from the equation:

$$SPC_p = (F_n - F_s)/t_p \quad (5)$$

Though in this scenario only variable costs have to be considered to calculate financial break-even, obviously, an operator will always attempt to realise a higher fee to obtain a maximum contribution to fixed costs. This illustrates again that calculated SPC's (especially in this unlimited scenario) can only be a first input to the operator in establishing a commercial gate fee.

## B.3 VARIABLE AND FIXED COST; RELATION WITH SPECIFIC PROCESSING COSTS

The specific processing costs in formula (3) have been derived pragmatically thusfar, but can also be related to more fundamental cost parameters.

### B.3.1 Variable cost element

In (heat or mass) limited cases, the annual fixed costs are not influenced by the substitution of $w$ times $t_p$ tonnes of grey waste by $t_p$ tonnes of P:

- as an existing plant is considered the annual capital costs are not affected by a change in waste feed;
- labour is constant if the overall mass flow is largely unaffected;
- maintenance is not influenced at maximum throughput.

Total annual fixed costs also remain constant if additional waste is accepted in an underloaded plant. (However, maintenance costs may slightly increase in this case, although the costs will be below the original figure at full throughput in the design situation.)
Fixed cost elements are included in both $F_n$ as $F_s$ at the same value and will consequently eliminate from their difference $F_n - F_s$. Therefore, this difference only includes variable cost elements. The expression $(F_n - F_s) / t_p$ in equation (3) reflects the additional (positive or negative) change in variable cost per tonne specific waste material P. It shows differences in residue disposal costs, electricity revenues, chemical consumption, etcetera, as P (with respect to grey waste) has a different ash content, heating value or elemental composition, requiring a different amount of process chemicals.
Taking these considerations into account, formula (3) can be simplified into:

$$SPC_p = (F_{v,n} - F_{v,s})/t_p + w * GF_g \qquad (6)$$

where:

$F_{v,n\ or\ s}$ variable annual cost in situation N or S [Dfl/year]

The difference in variable costs between situations N and S is caused by the addition of $t_p$ tonnes of P and the displacement of $t_g$ tonnes G.
Therefore:

$$F_{v,n} - F_{v,s} = t_p * v_p - t_g * v_g \qquad (7)$$

where:

$v_{p\ or\ g}$ variable cost per tonne P or G [Dfl/tonne]
$t_g$ tonnes of G displaced [tonnes/year]

Furthermore, the gate fee for the reference grey waste can be written as the sum of the variable and fixed cost, where the latter may be augmented to include a profit element:

$$GF_g = v_g + f_g \qquad (8)$$

where:

$f_g$ fixed cost per tonne G [Dfl/tonne]]

Combining formulae (1), (6), (7) and (8) gives:

$$SPC_p = (t_p*v_p - t_g*v_g) / t_p + (t_g/t_p) * (f_g + v_g)$$

or:

$$SPC_p = v_p + (t_g/t_p) * (-v_g + f_g + v_g)$$

thus:

$$SPC_p = v_p + w * f_g \quad (9)$$

In wording: the specific processing cost of an added waste material contains its variable cost plus a share in the fixed cost depending on the ratio between added P and displaced G.

### B.3.2 Fixed cost element

All fixed cost elements are introduced as part of $GF_g$, the second expression in formula (3) and explicitly through $f_g$ in formula (9).