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Solid recovered fuels - Determination of combustion behaviour

Feste Sekundärbrennstoffe - Bestimmung des Verbrennungsverhaltens

Combustibles solides de récupération - Détermination du comportement de la combustion

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English Version

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Feste Sekundärbrennstoffe - Bestimmung des Verbrennungsverhaltens

This Technical Report was approved by CEN on 21 January 2008. It has been drawn up by the Technical Committee CEN/TC 343.

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Contents

Page

Foreword.....	3
Introduction	4
1 Scope	7
2 Combustion of solid fuels.....	7
2.1 Basis of solid fuel combustion.....	7
2.2 Basics of some common combustion systems that utilises SRF	8
2.3 Determination of characteristic parameters	9
2.4 Use of classification numbers	10
2.5 Combustion prediction tool.....	10
3 Thermal gravimetric analysis	13
4 Standard fuel analysis.....	17
4.1 General.....	17
4.2 Proximate analysis: Moisture, volatiles, and ash content.....	17
4.3 Ultimate analysis: C, H, N, S, Halogens.....	17
4.4 Gross calorific value (GCV)/net calorific value (NCV).....	18
4.5 Particle size distribution.....	18
4.6 Ash content and ash melting behaviour	19
5 Advanced laboratory methods for fuel characterisation.....	19
5.1 General.....	19
5.2 Determination of fuel composition	21
5.3 Composition and calorific value of the volatile matter.....	22
5.4 Kinetic properties	25
5.5 Image analysis method for particle size distribution.....	30
5.6 Apparent densities of particles and intermediates	32
5.7 Aerodynamic lift velocity	33
5.8 Slagging and fouling behaviour	34
6 Operational behaviour in the combustion process.....	35
7 Summary.....	38
Bibliography	40

Foreword

This document (CEN/TR 15716:2008) has been prepared by Technical Committee CEN/TC 343 “Solid recovered fuels”, the secretariat of which is held by SFS.

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Introduction

Historically, SRF goes back to the oil crises approximately 30 years ago, when refused derived fuel (RDF) was promoted as a substitute low cost fuel. Contrary to that situation, the producers of SRF took the initiative for the implementation of a quality system to meet and guarantee specified fuel classification and specification parameters. Quality systems to check their production now exist in several EU member states and efforts are being made by CEN/TC 343 to develop European Standards for SRF [1].

The production and thermal utilisation (energy recovery) of Solid Recovered Fuels (SRF) from bio wastes, residues, mixed- and mono waste streams have significant relevance as a key component of an integrated waste management concept.

The implementation of SRF production in an integrated waste management concept demands a potential market for these products. Known proven markets are found in the European energy sector and in other more product-oriented sectors like cement or lime industry by substitution of fossil fuels. The capacities for co-utilisation of these products, to include utilisation in minor thermal shares, are enormous, especially in the new European member states as most of the energy production of these countries relies on fossil fuels.

A successful application of solid recovered fuel in power plants and industrial furnaces would require a thorough understanding of the fuel properties which include the combustion behaviour, emission potential, impact on facility etc. The determination of combustion behaviour which is the main focus of this document seeks to outline possible methods and procedures that can be adopted to analyse any given solid recovered fuel. An approach has therefore been outlined where the determination of combustion behaviour is categorised into four groups which combine to give a holistic impression of the combustion progress of SRF in both mono and co-firing systems (see Figure 1).

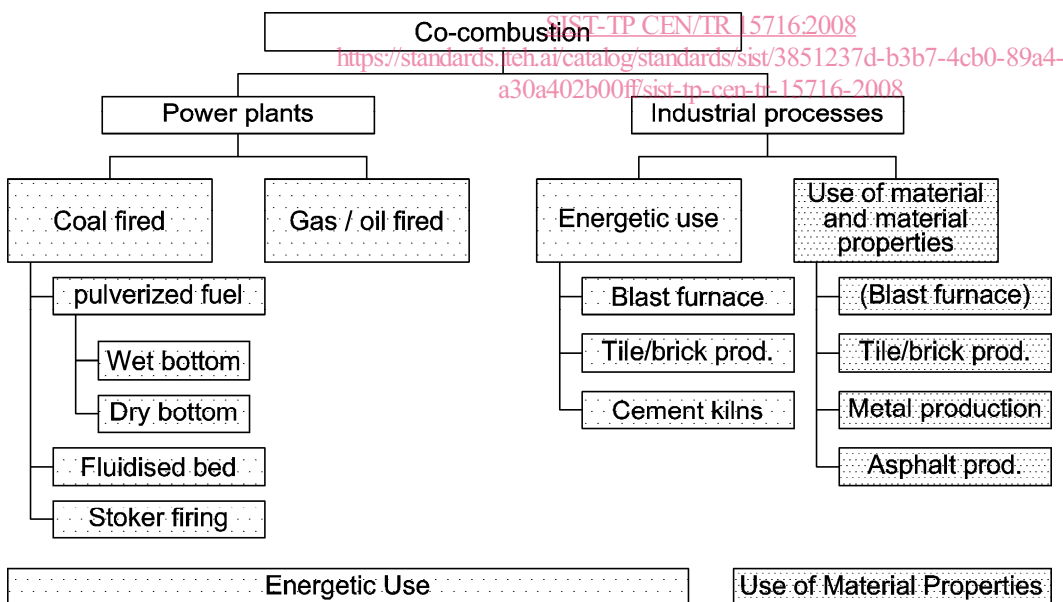


Figure 1 — Scheme to determine combustion behaviour of SRF

While there are standardised methods, such as from the American Society for Testing and Materials (ASTM) and the German Institute for Standardization (DIN Deutsches Institut für Normung e. V.), for determining combustion behaviour for primary fuels (e.g. coal), the process is not the same for SRF. At present, there are no standardised methods for SRF. Most of the available methods are in-house, usually designed for particular types of SRF, e.g. waste, or bio-residue fractions to suit a specific combustion system like grate firing, fluidised bed, pulverised fuel system, and cement kiln. Figure 2 gives an overview about the broad variety of

SRF utilisation routes using an example of co-combustion in power plants and industrial furnaces. Co-combustion also includes indirect co-firing systems such as gasification (Lahti, Zeltweg) and pyrolysis (ConTherm). While the environmental aspect of the thermal utilisation of SRF is very important, this report focuses only on the combustion aspect.

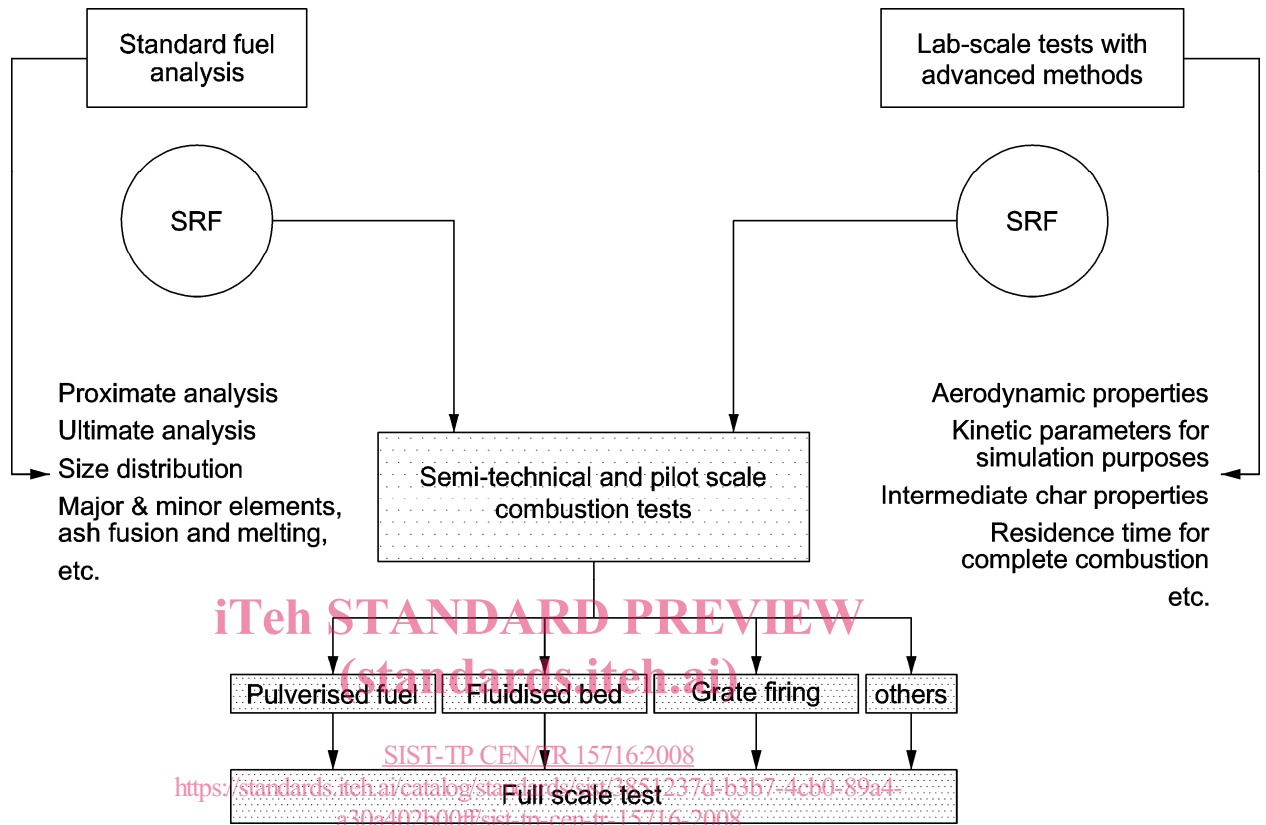


Figure 2 — SRF utilisation routes

Solid recovered fuel can be made of any combustible non-hazardous waste and processed to a quality that allows to classify it in accordance with CEN/TS 15359 and which fulfils specifications as agreed with the customer. Considering this, the main problem becomes obvious: How to define reliable methods to describe the combustion behaviour of solid fuels such as SRF, valid for all possible types of input material and combustion systems? A systematic approach adopted herein to determine combustion behaviour is outlined in Figure 1. It is grouped into four categories:

- standard fuel analysis;
- laboratory-scale tests with advanced methods;
- semi-technical and pilot-scale combustion tests;
- full-scale test.

In general, such a four-step procedure is an effective way to successfully integrate a new fuel in an existing power plant or an industrial furnace. In any case, full scale tests are the most reliable but very expensive with several bottlenecks (e.g. retrofits, permits, time, etc.) and that is the reason for the need to develop and standardise methods which are reliable, fast, and not expensive according to the various firing systems are essential. Besides the evaluation of parameters concerning combustion behaviour, the steps before full scale implementation also forms substantial basis to reliably evaluate other areas of major interest such as grinding and fuel feeding; slagging, fouling and corrosion; and lastly emissions and residues. The systematic evaluation of these additional topics requires area specific analyses, tests, and measurements.

Concerning combustion behaviour, the standard analysis of the SRF will determine the basic parameters about the combustible and incombustible matter. The amount of energy, the contents of water, volatiles, fixed-carbon, ash, and particle size will roughly dictate the type of the combustion system that is best suited. In addition to the standard analysis, a selected combustion system might require an advanced parameter analysis, if possible, with a close relation to case specific process parameters. Such a correlation will substantially enhance the reliability of transfer studies. An example, in the case of a pulverised firing system, is the maximum particle size required for a complete combustion in order to avoid fuel plummeting into the bottom ash.

Currently, the activities towards the combustion behaviour of SRF rely largely on standard analysis and laboratory-scale tests, which were originally developed with certain limitations and applicable to solid fuels such as lignite and hard coal. A common problem of these methods is that parameters related to SRF during combustion are not sufficiently covered. These methods make sure consistent quality of the SRF supply rather than to predict combustion performance. Therefore, the development of the so-called advanced test methods to fill the gap and amending existing test apparatus and measurement conditions is required.

The driving force to introduce SRF rests much on economic factors. In most cases, the end user will be either the operator of a power plant or an industrial furnace. The primary focus will be an unrestricted and reliable operation of the facility. One wants to assess the possible risks and dangers. In case of retrofits, the end user needs to calculate the required cost on modifications and operation. It can be assumed that due to possible operational risks such as corrosion, the plant operators will select the fuel with the most appropriate qualities. Such requirements are needed tools to control the quality of the SRF and to deliver them according to specification. As such, the knowledge of the combustion behaviour is an essential aspect for the commercialisation of SRF. It will allow the optimisation of the process and the assessment of possible risks and dangers prior to full-scale application.

Some methods and parameters will be introduced in the subsequent sections, but whatever methods are to be used in the future should be orientated towards the following aspects:

- reproducibility;
- repeatability;
- reliability;
- time efforts (rapid test methods);
- cost effectiveness;
- possibilities for automatic testing.

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The authors summarise and refer to past and current activities trying to describe combustion behaviour of SRF. The idea is to identify a common and successful practice where various approaches converge.

1 Scope

This Technical Report gives a review on determination methods for exploring how different SRFs behave in different combustion systems, e.g. with respect to time for ignition, time for gas phase burning and time for char burn out, including information on technical aspects like slagging and fouling, corrosion as well as required flue gas cleaning for meeting the emission limit values induced by the Waste Incineration Directive (WID).

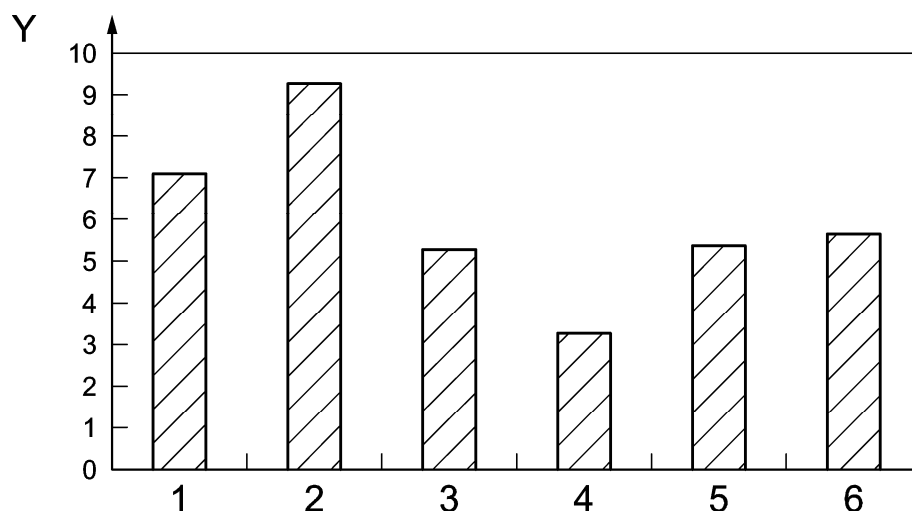
2 Combustion of solid fuels

2.1 Basis of solid fuel combustion

Combustion of fuels shall be considered both from theoretical and practical perspectives. The former can define combustion as the rapid chemical reaction of oxygen with the combustible elements of a fuel. While the later where the engineer is concerned with boiler design and performance might define combustion as the chemical union of fuel combustibles and the oxygen of the air, controlled at a rate that produces useful heat energy. The two definitions implicitly consider many key factors. For complete combustion within a furnace, four basic criteria shall be satisfied:

- 1) adequate quantity of air (oxygen) supplied to the fuel;
- 2) oxygen and fuel thoroughly mixed (turbulence);
- 3) fuel-air mixture maintained at or above the ignition temperature;
- 4) furnace volume large enough to give the mixture time for complete combustion.

Quantities of combustible constituents within the fuel vary by types. Figure 3 shows the significant change in the combustion air requirements for various fuels, resulting from changes in fuel composition. It illustrates the minimum combustion air theoretically required to support complete combustion.



Key

Y Stoichiometric air demand in nominal cubic meter dry air per kilogram fuel

Figure 3 —Stoichiometric air to fuel ratio for some SRFs

In an ideal situation, the combustion process would occur with the stoichiometric quantities of oxygen and a combustible based on underlying chemical principles. However, since complete mixing of air and fuel within the furnace is virtually impossible, excess air shall be supplied to the combustion process to ensure complete combustion. The amount of excess air that should be provided varies with the fuel, boiler load, and type of firing system, and it is in the range of $0,1 \leq \lambda \leq 0,6$ or even more.

Solid fuel combustion consists of three relatively distinct but overlapping phases:

- heating phase (time to ignition);
- gas phase combustion (time of gas phase burning);
- char combustion (time for char burnout).

Firstly, the time to ignition involves particle heat up due to radiation and convection in the furnace driving off moisture and volatiles adsorbed in the solid. Solid fuels, especially fresh biomass, can release combustible volatiles below 100°C and ignition can occur as soon as the particle is not completely surrounded by water vapour. The time to ignition is relatively short. For plastics it is different, they do not contain volatiles in the traditional meaning. They are often transparent so they heat up slowly and then start melting. Film plastics tend to shrink and form molten droplets. At about 400°C de-polymerization starts (pyrolysis) where gaseous combustible compounds release. The time to ignition is long compared to regular fuels of the same particle size. Secondly, the time of gas phase burning involves the volatiles released through desorption and pyrolysis burn in a flame around the particle until a solid char is left. This phase is long for plastics compared to coal because plastics (except PVC) do not form a char at all. The flaming particle can fly as a warm air balloon. Thirdly, the time for char burnout is a gas/solid reaction which for coal is the longest step and it is strongly dependent on particle size and porosity etc. For wood this is intermediate and for polyolefin plastics it is close to zero. The tests indicate that, for particles of the same size (50 mg) and same temperatures and oxygen contents, the time for complete burning is in the following order: plastics < dry wood < coal.

The combustion process of metals present in SRF especially aluminium is complicated and cannot be completely avoided. Ignition of such particles is preceded by the disruption of the oxide film at a temperature $> 1500^{\circ}\text{C}$ (calculated); it reacts intensively with atmospheric oxygen, which leads to a further sharp increase in temperature of the particle surface zone (see [2]). These high temperature regimes required to start the ignition are usually not found in conventional boilers, therefore the molten aluminium droplets coagulate and form large pieces upon cooling.

2.2 Basics of some common combustion systems that utilises SRF

Pulverised fuel combustion system (PF): In PF combustion, the fuel is ground to a specified fineness, e.g. coal to a maximum particle size of $250\ \mu\text{m}$ to $300\ \mu\text{m}$, depending on the reactivity. They are pneumatically transported to the burners and injected via particle-laden jets into the combustion chamber. For lower reactivity fuels, the fineness of grind is increased to create a larger specific surface area so as to improve conditions for ignition and combustion. The transport air that carries the fuel from the mill to the burners is a small fraction of the total combustion air. It is kept at low temperature, limited to about 373 K for coal and for SRF much lower, for reasons of safety against ignition and explosion in the mill and in the pulverized fuel transport pipeline between the mill and the burners. The rest of the combustion air, which can be preheated to higher temperatures, is injected separately and admixed with the already ignited particle-laden jet in the combustion chamber. The combustion chamber is typically of parallelepiped shape; the cross-sectional area of a 300-MW coal-fired boiler would be about $15\ \text{m} \times 15\ \text{m}$ and its height 45 m to 50 m (see [3]).

Fluidised Bed system: A fluidised bed is composed of fuel (coal, coke, biomass, SRF, etc.) and bed material (ash, sand and/or sorbent) contained within an atmospheric or pressurised vessel. The bed becomes fluidised when air or other gas flows upwards at a velocity sufficient to expand the bed. At low fluidising velocities ($0,9\ \text{m/s}$ to $3\ \text{m/s}$), relative high solid densities are maintained in the bed and only a small fraction of the solids are entrained from the bed. A fluidised bed that is operated in this range is referred to as a bubbling fluidising bed (BFB). As the fluidising velocity is increased, smaller particles are entrained in the gas stream and transported out of the bed. The bed surface becomes more diffuse and solids densities are reduced in the

bed. A fluidised bed that is operated at velocities in the range of 3,9 m/s to 6,7 m/s is referred to as circulating fluidised bed (CFB) (see [4]).

Fluidised bed combustion (FBC) units are touted as being „fuel flexible“, with the capacity of firing a wide range of solid fuel with varying heating value, ash content, and moisture content. Also, slagging and fouling tendencies are minimised in FBC units because of low combustion temperatures. The advantages of FBC in comparison to conventional pulverised fuelled units can be summarised as follows:

- SO₂ can be removed in the combustion process by adding limestone to the fluidised bed, eliminating the need for an external desulphurisation process;
- fluidised bed boilers are inherently fuel flexible and, with proper design provisions, can burn a variety of fuels;
- the combustion in FBC units takes place at temperatures below the ash fusion temperatures of most fuels, consequently, tendencies for slagging and fouling are reduced with FBC;
- because of the reduced combustion temperatures, NO_x emissions are inherently low.

Stoker firing system: In this firing system, solid fuel is spread and combusted on a grate system. The grate usually used is a continuous-cleaning, travelling grate. The lighter portion of the solid fuel burns in suspension above the grate and the heavier portion burns on the grate. Air and or water banks are used to cool the grate. Sometimes cooling is done by water. An over-fire combustion air is used to cause mixing of gases and combustion above the grate. This system is used predominantly for processed as well as unprocessed solid waste combustion. Other technologies used to generate heat and power from SRFs are explained in details elsewhere (see [5]).

2.3 Determination of characteristic parameters

Several researchers (see [6], [7], [8]) have shown that particle size and reactive surface have large influence on the combustion process, most especially SRF and solid biomass qualities available on the market. The distinctions between fuel properties and process conditions which contribute to the total combustion process are outlined in Table 1. Fuel properties and process parameters (operational conditions) together define how a particular SRF behave during combustion.

Table 1 — Fuel and process parameters influencing the combustion behaviour of SRF

Fuel properties	Process parameters
Heat capacity and conductivity	Temperature profile in the furnace
Gross calorific (GCV) and net calorific value (NCV)	Heat transfer in the furnace
Composition and distribution of organic and inorganic matter	Oxygen partial pressure along the furnace profile
Volatile release and char reactivity as a function of the particle temperature	Velocities, turbulence and mixing behaviour
Ash composition and ash fusion behaviour	Residence time
Fuel particle size etc.	Combustion system etc.

Solid fuel properties can be distinguished into chemical, mechanical (physical), calorific, and kinetic (reaction) properties. The chemical properties describe aspects like burnable substances, major and minor elements, etc. The mechanical properties describe particle and bulk densities, particle size distribution, shape and form, etc.; whereas the heating value, air demand, heat capacity and the calculated adiabatic flame temperature describe the calorific properties. These parameters can be transferred to SRF without restriction. The evaluation of kinetic properties is more difficult as they depend on chemical, mechanical, and calorific

properties. Contrary to the procedures used for coals, where detailed investigations towards the combustion properties are performed as a function of volatile content, heating value or particle size distribution, the approach even though not totally suitable for heterogeneous fuel can be adopted after a few modifications.

2.4 Use of classification numbers

Some parameters for the combustion behaviour of fuel are indicated by different classification numbers (see [9], [10]). This can be used to compare different primary and secondary fuels. Classification numbers are also published for other areas of interest such as slagging, fouling, corrosion and emission formation. A transfer of these numbers, which are mainly applied to different coal qualities, to SRF will have more limitation. However, it could be an option in the classification of SRF, although the interaction with coal in case of co-incinerator cannot be described sufficiently with this approach. Nevertheless, the approval of such classification numbers should include an independent validation procedure.

2.5 Combustion prediction tool

For the development and successful implementation of particle combustion models into combustion predicting tools, such as computational fluid dynamic (CFD) calculations, the kinetics of the fuel slagging; specifically volatile and char kinetic data are of great interest. The former is paramount if de-volatilisation is the rate determining step of the SRF during combustion, and vice versa. Most SRF have high volatile content, and during combustion their release dictates the process. Figures 4 and 5 illustrate the interactions in the combustion model as captured in CFD modules for plastics biomass and coal [11].

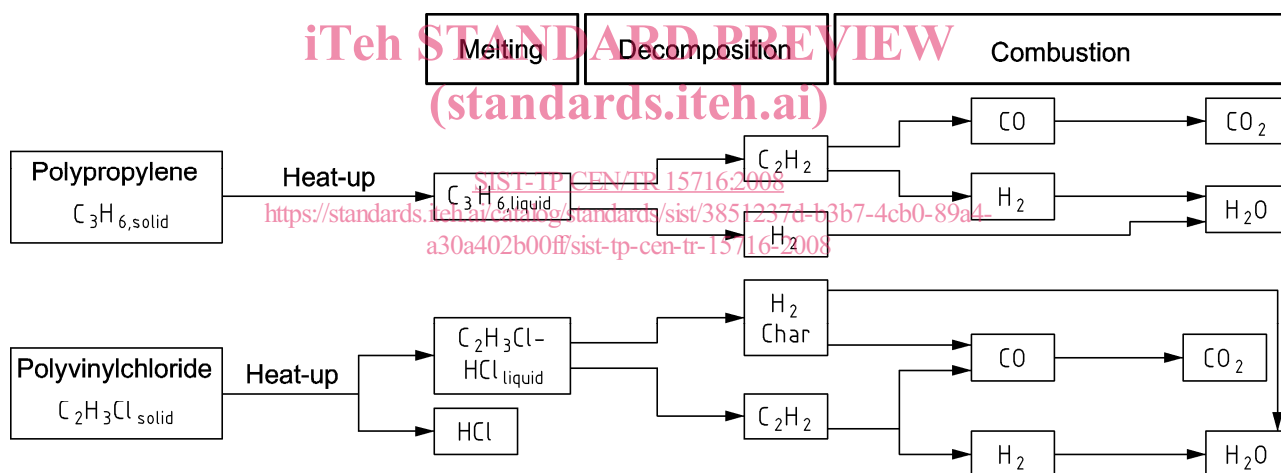


Figure 4 — Plastic combustion model [11]

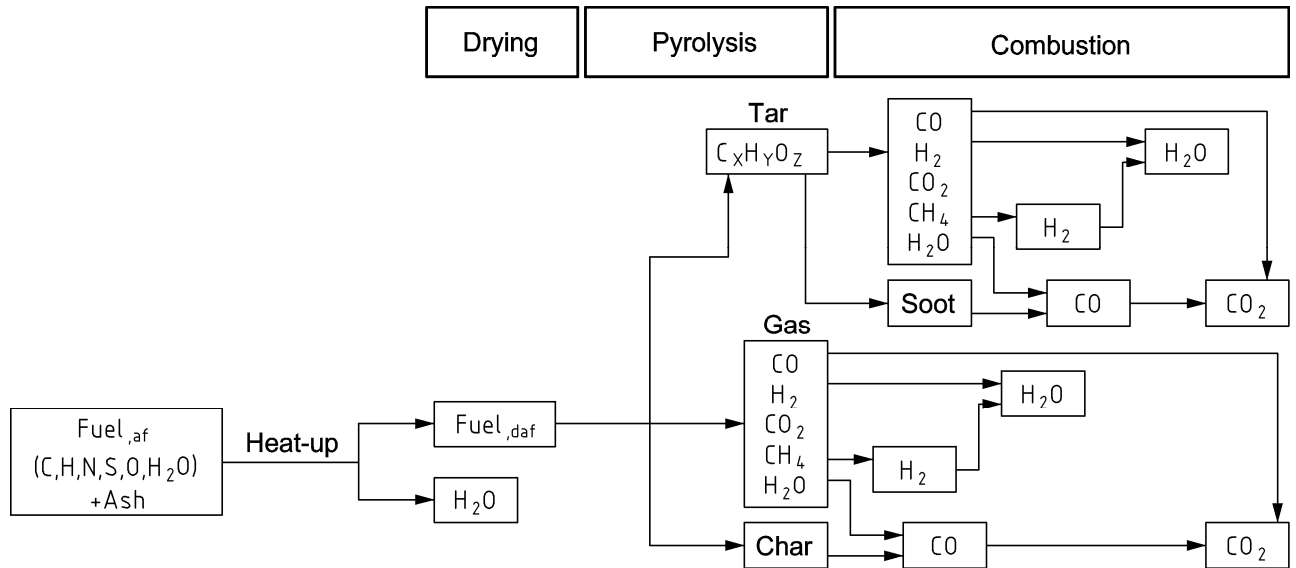


Figure 5 — Modelled reaction scheme for coal and biomass

The combustion of SRF like any other solid fuel can be simulated by way of adopting and modifying existing modules that have worked for pulverised coal combustion. The three primary phenomena that contribute to the predictions using CFD calculations are chemical reactions, flow behaviour, and heat transfer [12]. Figure 6 shows how such tools have been used to visualise burnout profiles of different SRF particle sizes in a boiler [13]. It shows that the burnout for larger particle sizes ($d_{50} = 5$ mm) were about 0,5 kg/kg_o according to the burnout colour code. Particle tracking has also been performed for coal, the biogenic and the plastic fraction of SRF and it is illustrated in Figure 7.

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