



Full Length Article

The prediction of the Gieseler characteristics of coal blends



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HIGHLIGHTS

- Easy and reliable prediction of Gieseler characteristics of a coal blend.
- Good prediction performance regardless the number of component coals.
- Identification of two main schemes of interaction between component coals.

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ABSTRACT

Prediction of plastic properties of blends is a prerequisite for optimal blend design since coke quality indices depend on them. 108 blends and their 121 components coals were characterized by Gieseler plastometry and used to test different models of prediction of the logarithm of maximum fluidity (LMF) of blends. Best results are obtained by the method of reconstruction of blend plastograms consisting in weight averaging the logarithm of fluidity of the component coals whose plastometric curves are approximated by two half-parabolas. Its performances improve with increasing number of components coals, probably due to the decrease in the resultant of all the possible interactions between coals. The softening and resolidification temperatures of blends can be expressed as a function of an “interaction parameter” which quantifies the fusion/solidification-retardant/accelerant effect induced by interactions between blend components. Because this interaction parameter does not change too much between softening and resolidification, plastic range (PR) is less sensitive to interactions than LMF and can be satisfactorily modelled by additivity but, from the only point of view of performance, LMF prediction is better than the PR one.

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1. Introduction

Coal blending is practiced not only to improve coke quality but also to use inferior coking coals, recycle low value carbon by-products, improve the coke yield and throughput while limiting the pressure developed during the process of carbonization. All these objectives clearly do not converge and the challenge facing the coke producer is in finding an increasingly subtle compromise between cost, quality, productivity and preservation of the battery.

The usual tool for blend design is empirical modelling. Since the plastic properties of the parent coal blend are among the factors controlling coke strength, the two parameters derived from the Gieseler plastometer test, i.e. the logarithm of maximum fluidity (LMF) and the plastic range (PR), naturally fall within the set of explanatory variables of quality prediction models:

- LMF: the transient liquid state not only improves coke stability by providing bonding to various coal components but also enhances growth of anisotropic domains particularly resistant to gasification.
- PR: in order to ensure optimum interaction between coal particles, it is important that the temperature intervals of the plastic state for coals constituting a blend should overlap. The longer the overlapping of maximum activity intervals of two particles, the more the number of chemical bonds formed in the contact area.

These parameters are given a heavy weighting in coke strength prediction formulas: Goscinski and Patalski reported in their review article that the partial derivative $\partial CSR / \partial LMF$ of the Kobe Steel CSR prediction formula is 7.8 [1]. The regression produced by BHP and provided by Pearson [2] gives a dependence of CSR on LMF of the same order of magnitude (8.5). Valia preferred to use the plastic range as rheological term and found a weighting

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Nomenclature

b	blend	R	gas constant ($\text{J mol}^{-1} \text{K}^{-1}$)
calc	calculated value	R_{or}	mean random rank or mean random vitrinite reflectance (%)
CSR	coke strength after reaction (wt%)	RMSE	root mean square error
E_{η}	activation energy for viscosity (J mol^{-1})	R2	correlation coefficient
F	Gieseler fluidity (dial division per minute or ddpm)	T	absolute temperature (K)
f_c	critical volume fraction of the solid phase at the gel point	TIC	total inert content (vol%)
f_s	volume fraction of the solid phase	T^{MF}	temperature at maximum fluidity ($^{\circ}\text{C}$)
i	coal index in blend	T^R	resolidification temperature ($^{\circ}\text{C}$)
It	inertinite (vol%)	T^S	softening temperature ($^{\circ}\text{C}$)
k, k_0 to k_4	fitting parameters	VM^{db}	volatile matter, dry basis (wt%)
k_A, k_B	pre-exponential factors of viscosity (Pa s)	Vt	vitrinite (vol%)
k_E	Einstein coefficient	WA	weighted average
LMF	logarithm of maximum fluidity ($\log_{10} MF$)	x_i	weight fraction of coal i in blend
Lt	liptinite (vol%)	y^R, y^S	Gaussian fitting parameters
M_e	molecular weight parameter (g)	α, β	interaction parameters expressing the deviation from additivity
M_w	average molecular weight of the liquid solvent (g)	η	dynamic viscosity of the suspension (Pa s)
MAE	mean absolute error	η_{liq}	dynamic viscosity of the liquid solvent (Pa s)
meas	measured value	μ	mean value
MF	maximum fluidity (dial division per minute or ddpm)	σ	standard deviation
n	number of coals in blend		
PR	plastic range ($^{\circ}\text{C}$)		

of 0.63 [3]. Converted to an equivalent value of LMF, given the linear relationship between LMF and PR, this coefficient is close to 10.

Unfortunately, of all the genetic properties, LMF and PR are the only ones to which additivity theoretically does not apply, in part because of the interactions between the component coals [4–6]. Consequently, the dependence of coke strength on rheology complicates the prediction of coke quality indices from the properties of the component coals and a fluidity prediction model becomes quite naturally the prerequisite for quality modelling.

Deviation from additivity, i.e. the difference between a blend property and its prediction deduced by weight averaging the properties of the component coals, can be ascribed to interactions between the components, provided that the property considered is inherently additive. Since the logarithm of the viscosity is considered additive at any given temperature [7], so is the logarithm of Gieseler fluidity [4,8]. Thus interactions between the coal components constituting the blend can be studied, at least qualitatively, based on the additivity of the logarithm of Gieseler fluidity.

This work is divided in two parts dealing with prediction of LMF and PR respectively. In the first part, three approaches previously reported in the literature are tested and compared: (i) the physical model of viscosity with its derived statistical formulation, (ii) the weighted averages of LMF corrected or not for the rank and (iii) the reconstruction of blend plastogram. The last method gives the best results but requires the plastograms of the component coals. In order to still be able to use it in case of unavailability of plastograms, a straightforward yet effective way of plastometric curve reconstruction is proposed. In the second part, the model of additivity of PR is tested. Both LMF and PR models are discussed in terms of interaction between component coals.

Synergism between coals and consecutive impact on fluidity have been extensively studied but primarily in binary and ternary blends, e.g. [4–6,9,10], specially prepared at the laboratory in order to vary the proportion of the coal components in the blend and the difference in genetic properties between them. Based on a hundred or so blends composed of 2–9 coals, this work proposes to add a third dimension to the issue of synergism: the number of component coals.

2. Experimental

2.1. Gieseler fluidity

In the steel industry, the Gieseler plastometry is a widely used standard method of measuring the fluidity of coal (ISO 10329:2009). It is essentially a rotating rabble arm stirrer held under constant torque in a packed sample of ground coal heated at $3^{\circ}\text{C}/\text{min}$ through the plastic range. The rate at which the stirrer rotates is inversely proportional to viscosity. Data obtained with the Gieseler plastometer are (1) softening temperature T^S (the temperature at which the stirrer begins to rotate), (2) temperature of maximum fluidity T^{MF} (the temperature at which the stirrer reaches its maximum rate), (3) resolidification temperature T^R (the temperature at which the stirrer stops), and (4) maximum fluidity MF (the maximum rate of stirrer movement in dial divisions per minute, or ddpm). The plastic range PR is defined as the positive difference between T^R and T^S . Plot of the fluidity versus temperature is called plastogram. The software of the plastometer used in this study does not allow for retrieving and exporting plastogram data files.

All Gieseler results are the average of duplicates. According to the standard test method, the margin of error, expressed in $\log_{10}$ (ddpm), is ± 0.15 if $MF < 20$ ddpm, ± 0.05 if $20 \leq MF \leq 10,000$, and ± 0.1 if $MF > 10,000$ ddpm. Note that an absolute error of 0.05 on the decimal logarithm of fluidity corresponds to a percent (relative) error of approximately 13% on the fluidity expressed in ddpm. The margin of error of the three characteristic temperatures of the test is $\pm 3.5^{\circ}\text{C}$.

2.2. Database

The database used in this study is provided by the Centre de Pyrolyse de Marienau at Forbach, France. It contains 108 blends prepared from 121 different single coals mainly from USA and Australia (Table 1). The six and seven-component blends account for roughly half of the population. It is worth noting that, on average, blending does not improve LMF and increases plastic range by only

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