Calculation of Replacement Ratio

The choice of coal for use as the injected fuel does impact significantly on the cost benefit that can be obtained by pulverised coal injection. The primary factor that influences the cost benefit of PCI is the amount of coke that can be replaced by the injected coal. Any coal can be injected with the main requirements, from the viewpoint of chemical analysis being low sulphur, ash content and minimum fluctuation in composition[1].

In Figure A1 the data from several sources has been plotted against the dry ash free carbon content which is a measure of the rank of a coal. In this figure all coal properties have been related back to the carbon content of the coal assuming a fixed ash content and using in-house relationships between coal properties.

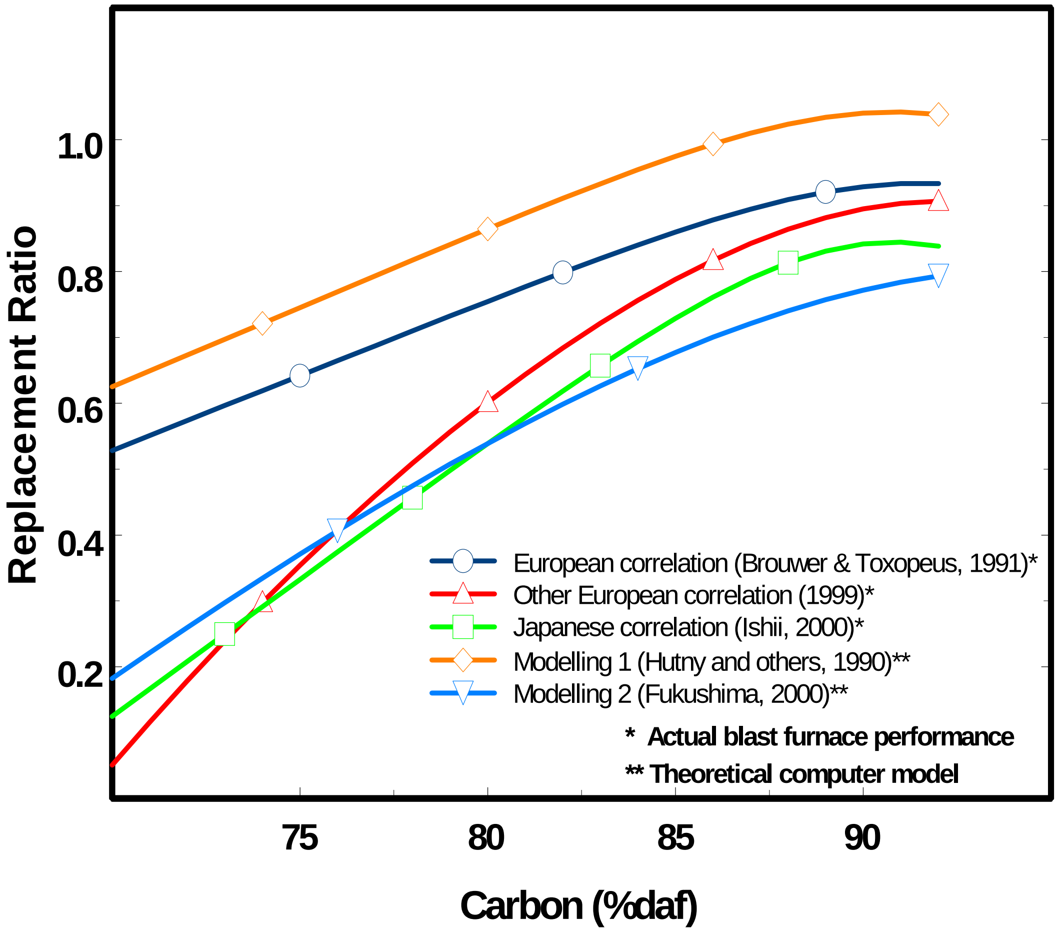

Figure A1 Variation of Replacement Ratio with coal rank

The replacement ratio normally quoted in the literature is the metallurgical corrected coke

[1] **Babich, A., Yaroshevskii, S., Formoso, A., Isidro, A., Ferreira, S., Cores, A., Garcia L., (1996),** Increase of pulverized coal use efficiency in blast furnace, *ISIJ International, Vol. 36, No. 10, 1996.*

rate where the coke rate is corrected for furnace parameters, such as hot metal silicon content, blast temperature, etc., to give coke rates under standard conditions. The theoretical coke replacement ratio is between 0.8 and 1.0 kg coke/kg coal depending on the energy and carbon content of the coal. Actual replacement ratios achieved in blast furnace operations with low to moderate injection rates tend to be slightly higher due to reduced heat losses and some increase in reduction efficiency. At higher rates over 150 kg/tHM heat losses can increase which may lead to replacement ratios that are lower than theoretical.

Hutny & others[2] (1990) have reported a general increase in replacement ratio with the C/H ratio of coal. They derived a relationship between the calorific value of the injected coal and replacement ratio, this relationship is:

$$RR = -0.6395 + 0.04 \times SE_{coal\,(daf)}$$

where	RR	fractional replacement rate
	SE	Specific Energy MJ/kg dry ash free.

Brouwer and Toxopeus[3] (1991) in summarising the PCI operating results at Hoogovens IJmuiden blast furnace derived a relationship between replacement ratio and the properties of the coal injected. This relationship is based on the dry carbon, hydrogen and ash percentage and is given below:

$$RR = \frac{-118.9 + 2.3 * C + 4.5 * H + 0.97 * ash}{100}$$

where	C	carbon % dry
	H	Hydrogen % dry
	ash	ash % dry.

The above relationship reinforces the conclusion reached by Hutny & others that replacement ratio increases with the rank of the coal. Though the positive effect of ash on replacement ratio is not what is expected.

In 1996 a European steelworks reported the use of a correlation which uses the volatile matter (dry basis) and the dry ash content to determine replacement ratio and given below:

$$RR = 1.14 - 0.014 \times Ash - 0.007 \times VM$$

where	VM	volatile matter % dry
	Ash	Ash % dry

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[2] **Hutny, W.P., Price, J.T. Gransden, J.F., (1990),** Evaluation of coals for blast furnace injection using a computer model, *Ironmaking Conf. Proc., 1990.*

[3] **Brouwer, R.C., Toxopeus, H.L., (1991),** Massive coal injection at Hoogovens IJmuiden BFs, Revue de Metallurgie. *Cahiers d'Informations Techniques, V88, N4, April 1991.*

In 1998 yet another European steelworks reported the following relationship for determining the replacement ratio.

$$RR = 0.06285 \times SE - 0.0544 \times H - 0.0104 \times C - 0.0169 \times Moist - 0.055$$

where	SE	Specific Energy MJ/kg dry
	H	Hydrogen % dry
	C	Carbon % dry
	Moist	Moisture % air dried

Ishii[4] examining the data from Japanese steelworks showed that the replacement ratio was related to the energy content of the injected coal.
Mr T. Fukishma of F-TeCon Pty Ltd carried out the modelling[5] to investigate the impact of PCI coal quality on the operation of a blast furnace. It was found that the partial heat of combustion was a good parameter to estimate the replacement ratio. The partial heat of combustion is the heat released when coal is gasified to CO and H_2 less the heat of decomposition of the volatile matter.
More recently Nippon Steel[6] [7] has shown that Calorific Value in Lower zone of BF (CVL) can be used to indicate the replacement ratio that can be obtained with a coal. The CVL is the partial combustion heat minus sensible heat of CO , H_2 and ash. CVL is defined as:

CVL = Available heat of PCI coal in lower part of BF above 1400°C
= Effective partial combustion heat above 1400°C
= (partial combustion heat) - (sensible heat of CO , H_2 and Ash)

[4] **Ishii, K., 2001,** Advanced Pulverized Coal Injection Technology and Blast Furnace Operation, Pub. Pergamon, UK, 2001

[5] **Bennett, P., Fukushima, T., 2003,** Impact of PCI Coal Quality on Blast Furnace Operations, 12th International Conference on Coal Science, Cairns, Australia, November 2003

[6] **Matsuzaki S.**, et al., CAMP-ISIJ Vol.17(April, 2004) p. 13

[7] **Orimoto T.**,et al., CAMP-ISIJ Vol.17(Sept., 2004) p. 631