Appendix A – Replacement Ratio of a Coal

Hutny & others[1] 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:

$$RR = -0.6395 + 0.04 \times SE$$

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

Brouwer and Toxopeus [2] 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:

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

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

[1] 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.

[2] 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[3] examining the data from Japanese steelworks showed that the replacement ratio was related to the energy content of the injected coal.

$$RR = 0.09 * SE_{dry}$$

where SE_{dry} Specific Energy MJ/kg dry

Fukishma[4] carried out the modeling 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.

$$RR = 0.354 \times Partial\ Heat\ of\ Combustion$$

More recently, Nippon Steel[5,6] 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. The best fit to Orimoto's data is:

$$RR = 0.065 \times CVL + 0.633$$

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

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

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

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