STUDY ON BASICITY IN DIRECT REDUCED IRON SMELTING

STUDI BASICITAS DALAM PELEBURAN DIRECT REDUCED IRON

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ABSTRACT

Pig iron as raw material for steel production, can be prepared by smelting a Direct Reduced Iron (DRI)/sponge iron. The smelting process needs optimum conditions to obtain such a high recovery likes basicity, which measures the ratio of alkalinity or acidity by adding the exact quantity of flux ($CaCO_3$) and quartz sand to input materials to generate the reduction process running well. In this study, smelting process was conducted using DRI sample mixed with varied flux ($CaCO_3$), quartz sand and coal. Then a mixture was fed to a resistance furnace. The reduction process was carried out at a temperature of 1600°C, for 1-2 hour. Pig iron as product and slag were analyzed to obtain its chemical composition. Afterward, recovery products was calculated. The results showed that the best conditions in these experiments were achieved at 1.18 basicity with pig iron recovery was reached up to 95.79%, contented of 95.84% Fe, 3.52% C and 0.0024% SiO_2. These data of this study can be used as reference of flux (limestone), quartz sand and carbon addition as input to resistance furnace in smelting process of sponge iron on a larger scale.

Keywords: DRI, basicity, pig iron, slag composition, FeO reduction

SARI

Besi wantah sebagai bahan baku baja, dapat dibuat dengan melebur besi spons. Proses peleburan ini perlu kondisi yang baik untuk mendapatkan jumlah perolehan yang tinggi diantaranya bacisitas yaitu mengukur rasio kebasaan atau keasaman agar jumlah fluks yang ditambahkan dengan jumlah tepat sehingga proses reduksi dapat berlangsung dengan baik. Pada penelitian ini peleburan dilakukan terhadap sampel DRI/besi spons dicampurkan dengan sejumlah fluks ($CaCO_3$) dan pasir kuarsa yang bervariasi untuk mengatur basicitas. Kemudian campuran spons besi dan kapur serta sedikit batubara diumpankan terhadap resistance furnace. Proses reduksi dilakukan pada temperatur 1600°C, selama 1-2 jam. Produk berbetuk besi wantah dan terak dianalisis komposisi kimianya dan jumlah perolehan besi dihitung. Hasil percobaan menunjukkan kondisi terbaik pada pencobaan ini dicapai pada basicitas 1,18 dengan perolehan Fe dalam besi wantah mencapai 95,79%, dengan komposisi besi wantah 95,84% Fe, 3,52% C dan 0,0024% SiO_2. Hasil penelitian ini dapat digunakan untuk referensi data penambahan fluks (kapur) dan karbon pada proses peleburan pada percobaan skala yang lebih besar.

Kata kunci: DRI, basicitas, besi wantah, komposisi terak, reduksi FeO

INTRODUCTION

Direct-reduced iron (DRI), also called sponge iron has the common characteristic that the oxygen was removed at temperature below the melting point of iron without melting the material in process and is produced from direct reduction of iron oxide process (in the form of a lumps, pellets or powder) with a reducing gas or coal. The reducing gas used is a mixture of gases such as hydrogen (H_2) and carbon monoxide (CO).

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Generally, iron and steelmaking consists of a sintering process or pelletization plants, coke ovens, blast furnaces and basic oxygen furnaces. Plant like this requires a high capital expenses and raw materials that have special specifications. Additionally, it needs coke as reducing agent which is not available in Indonesia. Direct reduction process is an alternative process, which is currently growing to replace the blast furnace, yielding DRI. There are some advantages and disadvantages of both process, which are showed in Table 1.

In the present, the country that the largest number producing direct-reduced iron in the world is India, with that meet the needs of the steel industry. Other countries produce for consumption in the domestic steel industries, like as China.

In smelting process, the raw materials of DRI need to be analyzed to obtain its chemical composition. This data is used to measure the ratio of alkalinity or acidity by adding right quantity fluxes to result the reduction process running well. In this case, basicity can be calculated from the chemical composition and metallurgical properties of the DRI. Straightfowardly, basicity defined as the ratio of alkaline oxides to the others non-ferrous oxides expressed as CaO/SiO_2 or $(CaO + MgO)/(SiO_2 + Al_2O_3)$ and the value varies from one tenth to 2-3.

DRI pellets produced by carbothermic process are composed of four main oxides CaO, MgO. SiO_2 and Al_2O_3. These oxides determined the basicity of the pellets as raw material for charging DRI into hot metal. Several studies have been conducted in the establishing basicity started from preparing feed pellets for blast furnaces or other furnaces. Sarkar et al, 2013, studied the utilization of fines generated ore into fluxed iron ore pellets inputing into a typical Mini Blast furnace (MBF). The maximum basicity of pellets was calculated 2.37 to make slag neutral when blast furnace runs at 100% high ash coke (avg. ash content = 29%). It was said that green crushing strength was decreased with increasing lime fines. The addition of lime fines as a burnt lime, which has acicular structure creates less plasticity and brittle like fracture occurred. Due to formation of hard $CaCO_3$ layer on the surface, after increasing lime contain crushing strength was increased in the air and oven dry pellets with respect to acid pellet (0% lime fines addition). In addition, Umadevi et al. 2011, studied in production pellets form the major part of the iron bearing feed to Corex and Blast Furnace. These pellets should be high strength, lower reduction degradation index to maintain good permeability of the bed to achieve high productivity and lower fuel rate. To produce good quality of pellets certain additives are important. The quality of the pellet is affected by the type of the raw materials, gangue content, and flux proportion and their subsequent treatment to produce pellets. Pellet with basicity 0.33 showed good physical as well metallurgical properties due to bonding phases present in the pellets. Whereas, Dwarapudi et al. 2011, studied effect of pellet basicity and MgO content on the melt formation and microstructure during the induration was examined Fired pellets with varying basicity (0 to 0.8) and MgO (0 and 1.5%) X-ray mapping was also

Table 1. The comparation of blast furnace versus direct reduced furnace

Item	Blast furnace	Direct reduction furnace
Reduction materials	Coke Cannot utilize coal directly/susceptible to pressure drop limitations	Coal Utilizes coal directly/not affected by pressure drop limitations
Energy	High	Low
Reaction used	Reduction with CO is slightly exothermic, reduction with H_2 slightly endothermic	Reaction strongly endothermic, external heat has to be supplied, e.g combustion of coal, electricity
Enviroment	High of CO_x, NO_x emision	Friendly emision, low of CO_x, NO_x emission
Mass and heat transfer	Excellent heat & mass exchanger	Poor heat & mass exchanger/ rotating vessel more complex than stationary shaft

carried out to understand the distribution of CaO, MgO, SiO_2 and Al_2O_3 indifferent phases. From the results, it was observed that with increasing basicity, RDI and softening–melting characteristics of pellets found to be improved. Improved pellet quality could be attributed to the formation of sufficient amount of silicate melt in basic pellets and high melting point slag in MgO pellets.

Beckett, 2002, studied activity coefficients of oxide components in the system CaO-MgO-Al_2O_3-SiO_2 (CMAS) with the model of Berman and used to explore large-scale relationships among these variables and between them and the liquid composition. On the basis of Berman's model, the natural logarithm of the activity coefficient of MgO, $\ln(\gamma_{MgO}{}^{Liq})$, and $\ln(\gamma_{MgO}{}^{Liq}/\gamma_{SiO_2}{}^{Liq})$ are nearly linear functions of $\ln(\gamma_{CaO}{}^{Liq})$. It was also mentioned that the correlations with optical basicity imply that the electron donor power is an important factor in determining the thermodynamic properties of aluminosilicate liquids.

Basidity can affect the softening and melting temperature on smelting direct reduced iron, such as Chuang et al. 2009, has studied the effects of basicity (the ratio between CaO and SiO_2) and FeO content on softening and melting temperatures of DRI residual. They concluded that the lowest softening and melting temperatures of the CaO-SiO_2-5%MgO-10%Al_2O_3 samples occurred at basicity of 0.55 while for the CaO-SiO_2-10-%MgO-5%Al_2O_3 samples it occurred at 0.70. This corresponds to the liquidus temperatures on the CaO-SiO_2-MgO-Al_2O_3 quaternary phase diagram. Liquidus is temperatute of material to initiate melt. At constant basicity, the deformation temperature of CaO-SiO_2-10%MgO-5%Al_2O_3 samples was found to be higher than that of CaOSiO_2-5%MgO-10%Al_2O_3 samples. Lastly, the addition of FeO below 20% to the CaO-SiO_2-MgO-Al_2O_3 system significantly decreased the softening and melting temperatures of the slag samples. In supporting that basicity of charge material has significant role. Zhao et al. 2012, studied high basicity coal-mixed pellets with basicity 2.2~2.4 and C/O molar ratio 1.1~1.2 are prepared to make iron nuggets through self-reduction 1300°C~1380°C with secondary iron-bearing dusts as raw materials. The main idea is to obtain pure iron nuggets from reducing high basicity pellets which is based on C and CaO of secondary iron-bearing dusts itself at a certain temperature. The iron nuggets do not contain gangues, the total desulfuration ratio is above 97% and total dephosphorization ratio is 50~60%, the main harmful elements of K, Na, Pb, Zn is totally removed approximately. This previous study mainly provides a new technique for recovering dusts and an effective measure for energy conservation, emission reduction and environmental contamination.

Addition of MgO will affect to the smelting temperature as well as slag viscosity. Zhang, et.al., 2012 mentioned that increasing the concentration of MgO will slightly decrease the liquidus temperature. Decreasing the concentration of MgO can also decrease the liquidus temperature. In other word, the liquidus temperatures can be kept the same for high Al_2O_3 slag if MgO concentration is decreased. Gao et.al, 2014, studied effect of MgO content on the viscosity of slag. The basicity increase to be increasing of the MgO content that cause decreasing the viscosity of the slag. At lower temperature, the increase of basicity or MgO content does decrease the viscosity of the slag, as it does not at higher temperatures. The calculated activation energy of viscous flow is between 154 and 200 kJ•mol−1, which decreases with an increase in basicity from 0.4 to 1.0 at a fixed MgO content in the range of 13wt% to 19wt%.

Slag properties can be used to indicate the removed unwanted elements from the metal and purify the metal by forming oxides and floating them off the molten metal. Several experiments on slag, like Bafghi et al. 1992, has been conducted a kinetic study on the reduction of iron oxide in molten slag with graphite. The condition of the experiment was basicity 1-2 and temperature 1300°C. It is stated that the reaction rate is significantly affected by the slag composition. Meraikib, M., 2003, conducted test trials in a 70 t ultrahigh power (UHP) electric arc furnace. The proportion of DRI in the charge varied between 40 and 95%. Slag samples were taken at various time intervals and analysed. The analyses were used for estimating the activity of alumina in the slag. The activity was correlated with the basicity, temperature and DRI proportion in the charge. The results of correlation show that the activity is mainly dependent on the basicity of the slag. It is inversely proportional to the basicity and increases as the temperature rises. The activity increases by $3{\bullet}8\times10^{-4}$ for every 10% increase in DRI proportion in the charge.

The purpose of this study is to investigate basicity variation in processing DRI into pig iron to obtain the best conditions in achieving a high quality product as well as its recovery, since currently relatively a little research has been conducted to investigate the basicity on pig iron production in Indonesia due to its distinctive iron minerals. This results can be used as a reference in the application of larger-scale trials.

METHODOLOGY

Sample used for this study was DRI contented of 90.45% Fetot , 85.43% Femetal, 5.02% Fe in Fe-oxide and 94.45% metallization. The degee of metallization as suggested by Satyendra (2013) for DRI smelting were 83-95 %. While the impurities content of 2.01% SiO2, 1.54 Al_2O_3, 0.75% MgO, 0.001% P_2O_5 and 0.43% Stot. The sponge iron was ground and mixed with a varies of fluxes ($CaCO_3$) and quartz sand as correction to determine basicity and a suitable amount of coal as a reducing agent of iron oxide in the sponge iron was also added. It was fed to the resistance furnace to be smelted. The feed charges of materials into resintance furnace are showed in Table 2. The reduction process was accomplished on temperature 1600°C, for 1-2 hour. Tapping of molten iron was conducted after the fluidity of slag was quite large amount. The pig iron as a product of the smelting process was analyzed by spectrophotometry and the recovery of metalization was calculated. While the slag was analyzed by AAS.

In this experiment, energy used for each smelting tests was recorded by undigitalized kWh/meter to investigate the energy consumed of DRI smelting with different bacisity conditions.

RESULTS AND DISCUSSION

The experiments were performed by varying basicity (V), which is the ratio of basic oxides (CaO + MgO) with an acidic oxides (SiO_2 + Al_2O_3). This basicity condition is very important in DRI smelting, to produce pig iron with a high recovery. In general, the pig iron making process using DRI as raw material is produced from a shaft furnace, with natural gas as reducing agent (gas-based reduction) applying basicity of 0.1, 0.5 or 0.6. Whereas, DRI produced with coal as reducing agent (coal-based reduction) in a rotary hearth furnace, uses basicity of 0.06. In addition, DRI produced from a rotary kiln, uses basicity of 0.1. In the rotary hearth furnace, reduction process is accomplished in high temperature 1300-1500°C to form semisolid slag and a high SiO_2 content is governed of that condition. On the other hand, in rotary kiln process, basicity of slag does not have important role on metalization degree in yielding DRI.

Basicity calculation: In these experiments, DRI was formed into pellets, with varies basicity conditions, V = 0.49, 0.50, 0.64, 0.69, 0.89, 1.07, 1.22, 1.52, 1.67 and 1.82 [as shown in] Table 1. However, the experimental conditions for basicity equal to 0.06 and 0.1 was excluded since a very large amount of SiO_2 addition will needed and the sample size will not suitable for smelting

In a DRI smelting process, the addition of limestone ($CaCO_3$) is intended to adjust the basicity which greatly affects to the slag fluidity, viscosity and the ability to sulphur removal. The calculation of the limes, quartz and coal addition to adjust

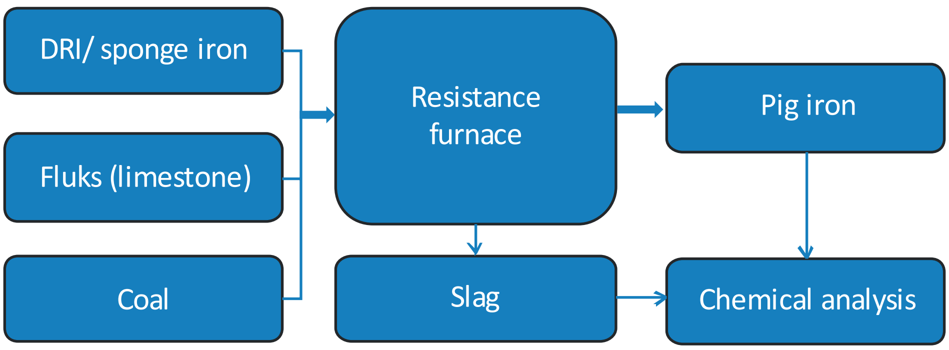

Figure 1. Flow chart illustrates the experiments

basicity is shown in Table 2. It was assumed that 5% Fe went into the slag.

The carbon addition is also required to neutralize the FeO content in the DRI. The amount of carbon needs to react with air in the DRI to reduce FeO is 0.215% C for 1% Fe in the formed as FeO. The reduction reaction is as follows (Anonym):

FeO0,95O + C = Fe + CO .... (1)

C. The total amount of impurities elements such as Ni, Cr, Cu, etc. are below 1 %.

The effects of basicity on recovery and Fe content are showed on Figure 2. Both of the recovery and iron content rise in line with increasing basicity, starting from basicity of 0.49 to achieve the best conditions on the basicity 1.18, then its dropped at basicity 1.82. It is clear that the limestone addition, for basicity–CaO/SiO_2 of charge material

Table 2. Calculation of material needs for DRI smelting

Components				Basicity									
DRI, g		1000	g	0.49	0.50	0.64	0.69	0.89	1.07	1.22	1.52	1.67	1.82
Fe tot,%	90.45	899.98	g						(%)				
SiO_2,%	2.01	20.1	g	47.46	46.76	38.65	36.21	27.61	24.32	22.89	20.51	19.51	18.61
Al_2O_3,%	1.54	15.4	g	13.45	13.63	15.71	16.33	18.54	17.96	16.84	14.97	14.18	13.47
MgO,%	0.75	7.5	g	6.55	6.64	7.65	7.95	9.03	8.75	8.20	7.29	6.91	6.56
P_2O_5,%	0.001	0.01	g	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
S,%	0.43	4.3	g	3.76	3.81	4.39	4.56	5.18	5.02	4.70	4.18	3.96	3.76
CaO,%	2.65	26.5	g	23.15	23.46	27.04	28.11	31.90	36.44	40.32	46.79	49.51	51.97
FeO,%	6.43		g	5.62	5.69	6.56	6.82	7.74	7.50	7.03	6.25	5.92	5.62
Total	80.24		g	100	100	100	100	100	100	100	100	100	100
Coal,%	4.5		g										
SiO_2 in coal, g		0.68	g						Limestone and quartz added				
$CaCO_3$, 96% CaO				0.00	0.00	0.00	0.00	0.00	4.83	10.58	22.08	27.83	33.58
CaO,g									4.74	10.37	21.64	27.28	32.91
SiO_2 in $CaCO_3$				0.00	0.00	0.00	0.00	0.00	0.07	0.16	0.33	0.42	0.50
Quartz 95% SiO_2				33.55	32.05	17.11	13.37	2.16	0.00	0.00	0.00	0.00	0.00
Total gangue materials				114.46	112.97	98.02	94.28	83.07	85.72	91.44	102.89	108.61	114.33

Hence, the DRI samples contented 90.45% Fe total and 94.45% metallization will be required 1.94% carbon or 4.5% coal with 43% fixed carbon content. The calculation is as follow (Anonym):

(100% -90.45% Fe_{total}) x (94.45% Met / 100) x 0.215 = 1.94 .... (2)

Pig iron as smelting product: Table 3 shows the chemical composition of pig iron. The pig irons content of 92.99 - 95.84% Fe and 3.51 - 6.15%

will influence the temperature and the amount of melt formed in smelting process. The properties of the pellets are, largely governed by the form and degree of bonding achieved between ore particles and also by the stability of these bonding phases during the reduction of iron oxides. From the test result it was clear that pellet properties were influenced by the bonding phases present in the pellet and it suggests that the reduction of FeO tends to occur more favourable in alkaline condition beside of acid condition. The best conditions in this trial was achieved at 1.18 basicity with recovery of 95.84% and iron content reached up to 89.95%, as shown in Table 3.

The best quality of pig iron contents of 95.84% Fe, 3.52% C and 0.0024% SiO_2. In certain circumstances, the absence of silica in the pig iron occured in the basicity of 0.81 and 0.96 (acid condition). Similarly, silica loss happened in pig iron when the basicity of 1.47 and 1.81 (base condition) (Figure 3). The loss of silica in the pig iron is very risky since it will affect the molten pig iron to quickly freeze, consequently it will create the difficulty in refining process to produce steel.

Slag analysis : Basicity slag produced relatively the same as the charge material as shown in Table 4 and Figure 4. The slag contained of Fe less than 10%.

Slag from smelting product need to be analyzed, as slag indicated the removed unwanted elements from the metal and purify the metal by forming oxides and floating them off the molten metal. Slag usually consists of metals oxides and acts as a destination for impurities, a thermal blanket (stopping exessive heat loss) and an errosion reducer for the refractory lining of the furnace (Bruker, 2013).

Slag analysis are shown in Figure 4 and Figure 5. The slag still containing iron. It was 4.46 – 9.97% Fe. The data of iron content in slags, can be used as an assuming value for basicity calculation. In this case the experiment was calculated by assuming a slag containing 5% Fe. Other materials which are dominant in the slags, first is silica which decreases with increasing basicity. This correlates to the silica added when the DRI pelllets

Table 3. Chemical analyses of pig iron, produced by DRI smelting with different basicity

	Basicity									
	0.46	0.56	0.65	0.67	0.81	0.96	1.18	1.47	1.61	1.81
Metal, g	840.88	842.13	847.88	856.48	887.15	892.84	899.50	861.21	859.04	846.25
Rec, Fe,%	86.89	88.41	89.29	90.38	93.24	94.84	95.79	91.33	91.23	89.74
Yield, %	84.09	84.21	84.79	85.65	88.72	89.28	89.95	86.12	85.90	84.63
C	6.15600	4.72583	4.71153	4.45008	5.09620	3.97684	3.51944	4.10258	3.84204	4.10258
Si	0.03419	0.04382	0.02807	0.02200	0.00000	0.00000	0.00235	0.00000	0.04493	0.00000
S	0.34512	0.37599	0.45759	0.50900	0.29935	0.36704	0.45777	0.42534	0.45900	0.42534
P	0.00482	0.00877	0.00594	0.00470	0.00564	0.00769	0.00740	0.00555	0.00488	0.00555
Mn	0.00327	0.00192	0.00275	0.01070	0.00146	0.00087	0.00164	0.00250	0.00920	0.00250
Ni	0.37577	0.28009	0.00283	0.00789	0.00318	0.03652	0.11720	0.00372	0.00620	0.00372
Cr	0.03914	0.03815	0.00785	0.00411	0.00318	0.00892	0.01780	0.00515	0.00951	0.00515
Mo	0.00413	0.00337	0.00326	0.00037	0.00333	0.00353	0.00456	0.00431	0.00492	0.00431
V	0.00153	0.00029	0.00000	0.12370	0.00044	0.00001	0.00122	0.00031	0.00143	0.00031
Cu	0.01647	0.04045	0.00980	0.00295	0.01044	0.00897	0.01115	0.00642	0.01669	0.00642
W	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ti	0.00058	0.00000	0.00000	0.00000	0.00000	0.00000	0.00319	0.00000	0.00098	0.00000
Sn	0.00249	0.00609	0.00206	0.00295	0.00235	0.00201	0.00526	0.00330	0.00352	0.00330
Al	0.00642	0.00381	0.00506	0.00367	0.00386	0.00381	0.00622	0.00428	0.00738	0.00428
Pb	0.00000	0.00190	0.00131	0.00107	0.00342	0.00198	0.00000	0.00190	0.00268	0.00190
Sb	0.00199	0.00000	0.00000	0.00353	0.00000	0.00000	0.00291	0.00247	0.00541	0.00247
Nb	0.00000	0.00019	0.00000	0.00000	0.00102	0.00114	0.00089	0.00000	0.00018	0.00000
Mg	0.00594	0.00000	0.00000	0.00097	0.00000	0.00000	0.00089	0.00172	0.00322	0.00172
Zn	0.00857	0,.00186	0.00093	0.00205	0.00351	0.00213	0.00067	0.00247	0.00381	0.00247
Fe, %	92.99451	94.48145	94.77635	94.96529	94.58737	95.59465	95.84483	95.43954	95.57664	95.43954

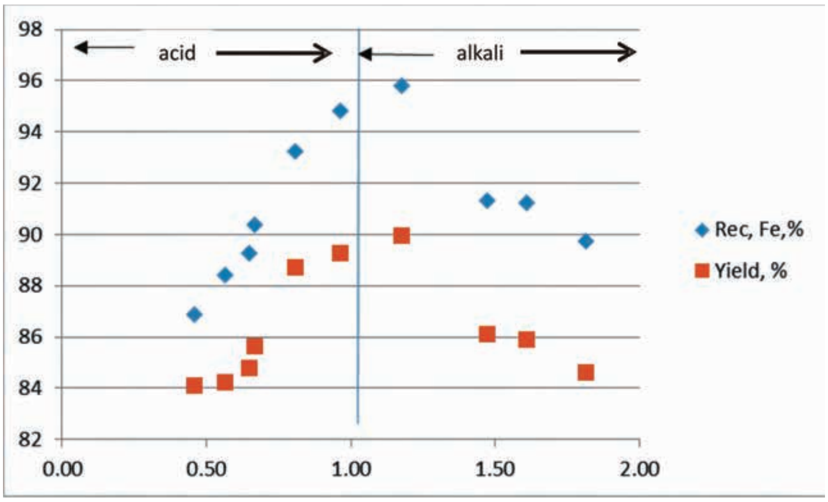

Figure 2. Effect of basicity to recovery and iron content on pig iron

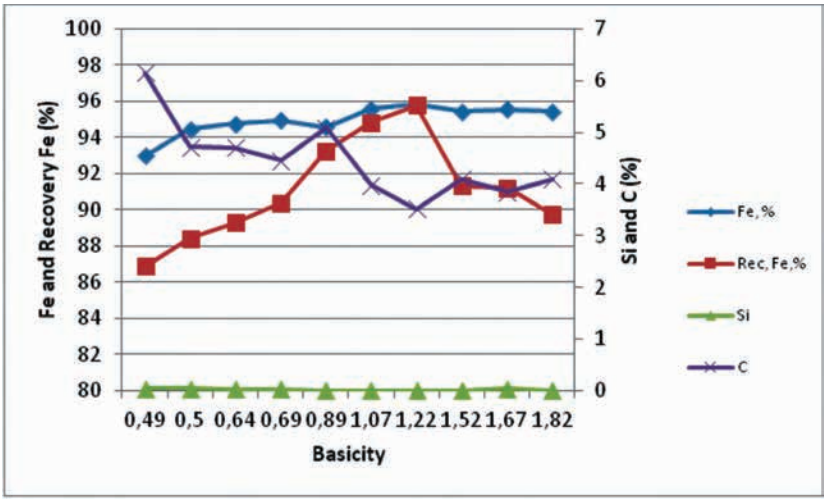

Figure 3. The chemical composition of pig iron

Table 4. Slag composition [analyses]

	Basicity									
	0.46	0.56	0.65	0.67	0.81	0.96	1.18	1.47	1.61	1.81
Fe_{tot}, %	6.28	9.07	7.26	4.60	9.97	6.58	6.34	6.96	9.13	6.06
SiO_2, %	52.00	46.70	44.70	49.20	43.50	39.70	33.10	27.70	24.20	23.70
Al_2O_3, %	11.04	9.81	10.34	7.28	4.70	6.95	9.08	9.14	9.63	9.06
MgO, %	2.80	3.24	2.92	5.15	5.14	3.98	3.21	3.61	2.73	3.28
FeO, %	8.07	11.66	9.33	5.91	12.82	8.46	8.,15	8.95	11.74	7.79
CaO, %	26.09	28.59	32.71	32.46	33.84	40.91	46.46	50.60	51.70	56.17
total, %	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
slag weight, g	182.8	177.72	160.67	149.93	104.43	102.99	80.14	84.36	140.96	116.69

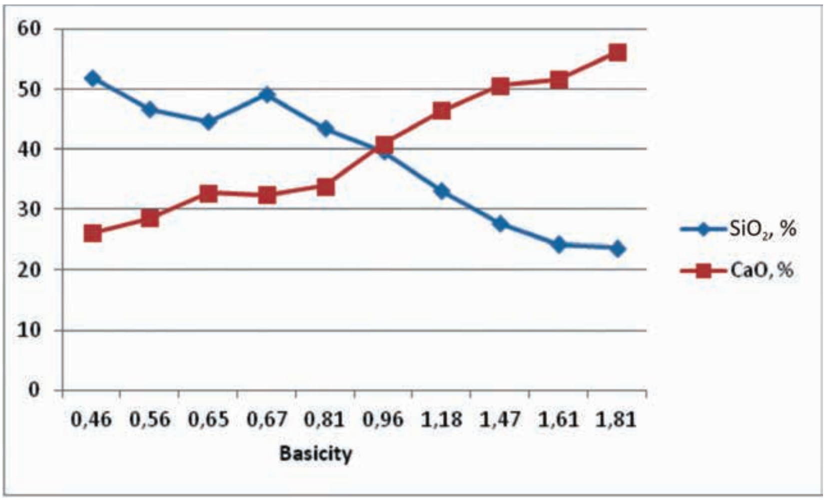

Figure 4. SiO_2 and CaO content on slag composisition

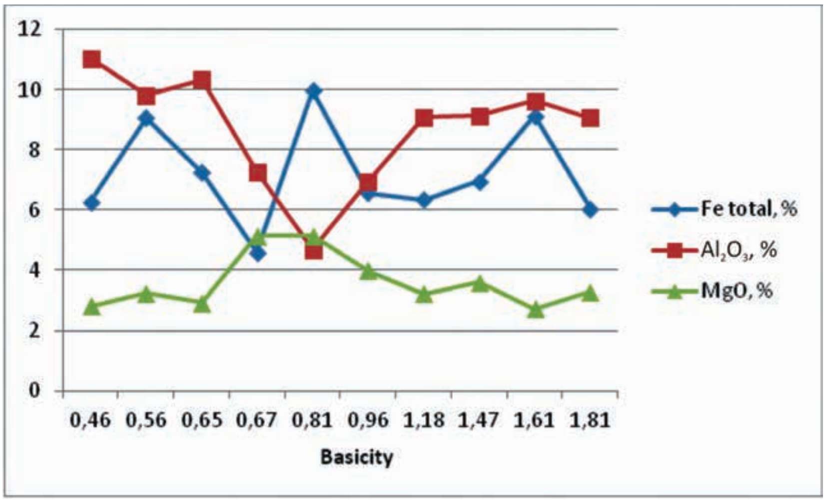

Figure 5. Fe_{tot}, Al_2O_3 and MgO content on slag composisition

were formed. Similarly, CaO content in the slags increase with increasing basicity This relates to the addition of lime.

The gangue oxides contented in the DRI (SiO_2, Al_2O_3, MgO, CaO, P, S) was greatly affect to the energy consumed as well as to metal quality in pig iron. The higher gangue especially SiO_2 in DRI, the higher the energy consumed and less pig iron produced. This statement is supported by the experiments accomplished by Chuang, et.al., 2010, It shows that the addition of 5% SiO2 changed the slag composition and decreased the slag basicity to 0.89. Therefore, the liquidus temperature of the slag was decrease to around 1380°C (Ternary diagram of CaO-SiO_2-5%MgO-Al_2O_3 phase system in Figure 6, point b. Therefore, the reaction temperature is below the liquidus temperature of the slag.

In Appying the experiment results into ternary diagram, the optimum basicity value of the experiments (V =1,18) is plotted to point red dot, which is shown in Figure 6. This means the liquidus temperature is high in range 1500-1600°C. This condition consumes higher energy, compared to the condition of 5% MgO added to the charging materials, as Chuang experiments. Meanwhile, Ghosh, 2010, experiments resulted the increasing of alumina and lime content as increasing the liquidus temperature in smelting of iron ore using blast furnace.

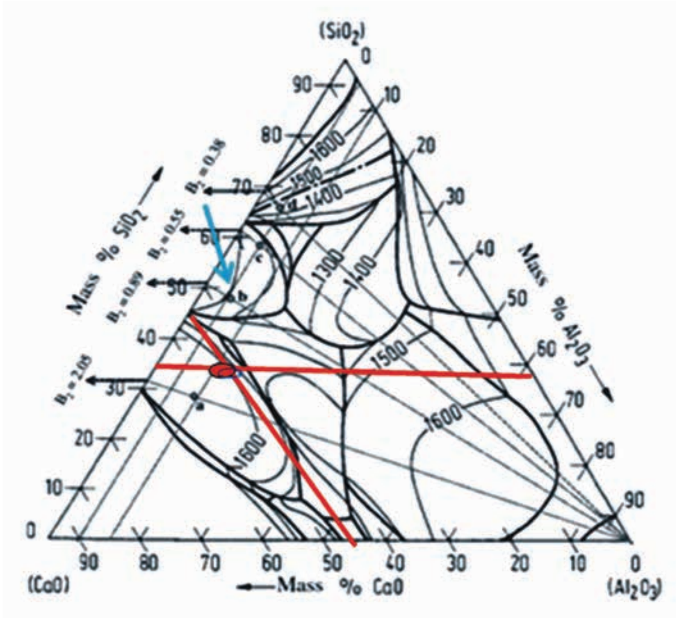

Figure 6. Ternary diagram of slag (Chuang et al,2010)

Energy consumed on smelting process: Percentage of metallization in DRI will affect to energy consumption. The lower metallization will cause the higher FeO content. This will consume higher energy for smelting, compared to higher metallization of DRI. Chemical reduction of FeO is an endothermic reaction.

Kipepe, 2014, mentioned that the addition of CaO would affect the basicity value and would result in energy consumption. As It is shown in Figure 7, while the basicity value was 1.8, 620 kWh/t energy was consumed. In line with the icreased basicity values from 1.8 to 2.1, then the energy consumption decreased from 620 kWh/t to 590 kWh/t. Afterward the basicity values increased from 2.1 to 2.5, the energy consumption increased from 590 kWh / t to 610 kWh / t.

Similiarly condition, in nikel sulfide concentrate smelting that contained of copper in submerge eletric arc furnace, when the basicity value increases from 0.6 to 0.85, will cause the energy consumption decreases. This can be used for prediction the energy need to produce per ton of nickel matte (Figure 8).

DRI and scrap additions for steel industry are very imporrtant since it can lower energy consumption during smelting process. A model of the EAF energy efficiency based on a closed mass and energy balance of the EAF melting process was developed by Kirschen et al, 2011. This model was applied to industrial EAFs in steel industry charged with scrap or with mixes of scrap and DRI. In this research, some experiments were accomplised to measure energy consumption

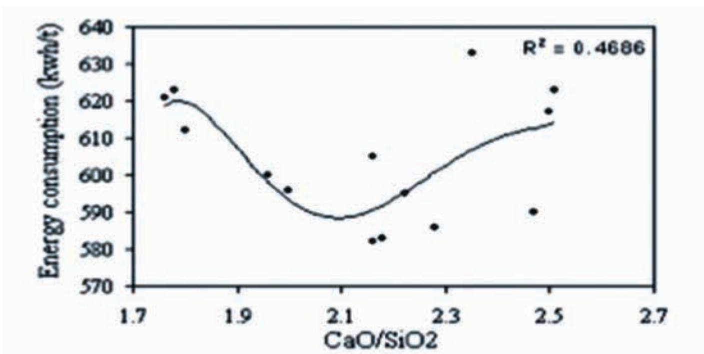

Figure 7. Effect basicity to energy consumption of DRI smelting (Kipepe, 2014)

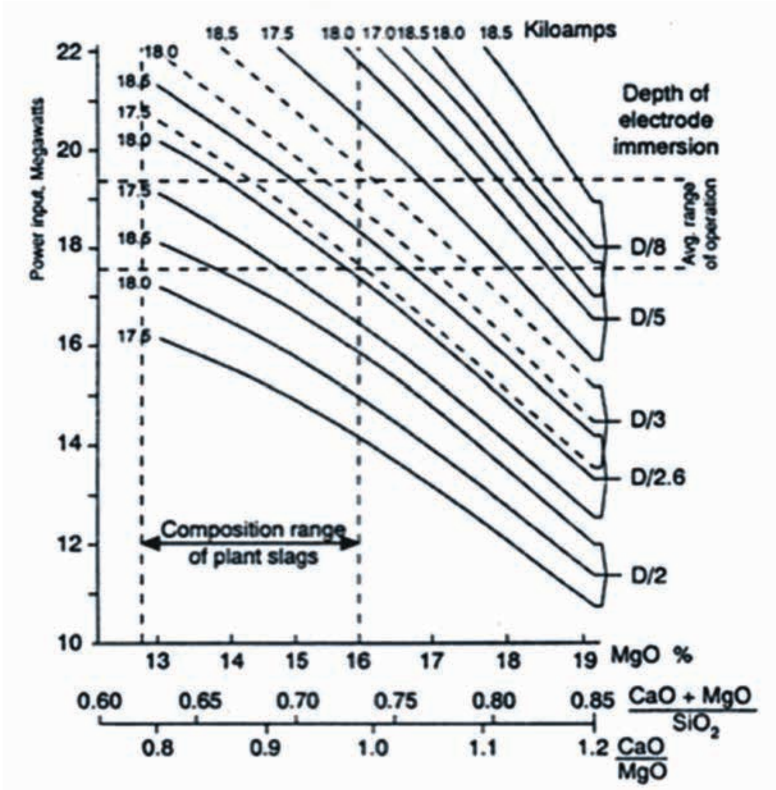

Figure 8: The effect of basicity in producing nickel matte from nickel sulfide concentrate to energy consumption of smelting (Eric, 2004)

during smelting process of DRI to figure out the relationship between energy consumnption and bacisity of DRI. Figure 9 and Table 5 show that the lower basicity requires a higher smelting energy compared to higher basicity (alkaline conditions). This is due to silica content which greatly affect to the melting point of DRI pellets. The best result for DRI smelting were recorded at the basicity of 1.18, that in producing 1 ton of pig iron required 1.06 MW.

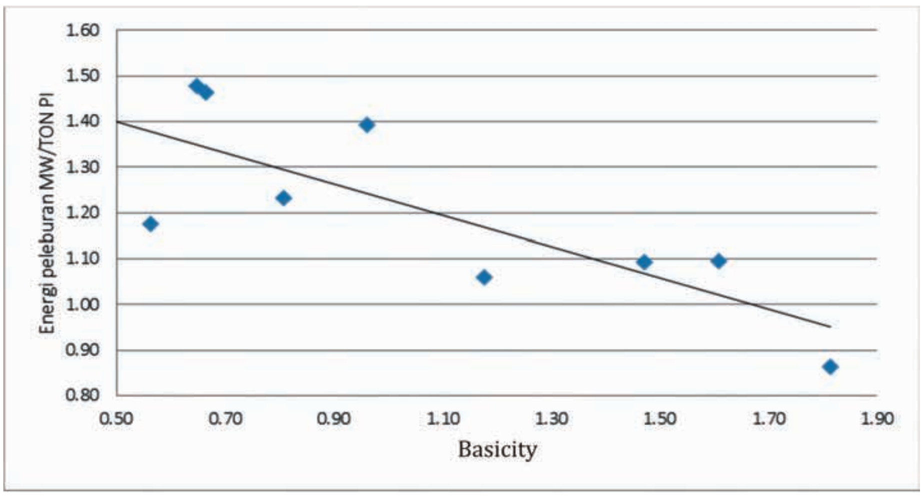

Figure 9. The relationship between energy consumed and basicity in smelting DRI

Table 5. Energy needed for DRI smelting with different basicity

MW/TON PIG IRON	1.37	1.18	1.48	1.46	1.23	1.39	1.06	1.09	1.09	0.86
BASICITY	0.46	0,56	0.65	0.67	0.81	0.96	1.18	1.47	1.61	1.81

CONCLUSION

DRI melting experiments carried out with varying basicity of 0.46 to 1.91. The best conditions to achieve were at the basicity of 1.18 with the recovery of 95.84% Fe and the pig iron contained 89.95% Fe.

The slag still containing iron. It was 4.46 – 9.97% Fe. Other material which is dominant in the slag, is silica which decreases with increasing basicity and CaO content rises with increasing basicity. This relates to the addition of lime.

The energy required to smelt the DRI samples, indicates that the lower basicity consumed higher energy is compared to higher basicity value. The energy required in basicity of 1.18 is 1.08 MW for one ton of pig iron. To achieve basidity of 1.16, the addition of lime approximately 4% of the weight of the DRI.

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