

I'll Huff and I'll Puff...

Observations on Air Delivery in Bloomery Iron Furnaces



How it Works

Puzzle of Historic Air

When Data doesn't fit Hypothesis

Darrell Markewitz The Wareham Forge

Forward Into the Past 23 - 2013





Chemistry is STANDARD

- Fire Proof Container
- Burning Charcoal
- Iron Oxide Ore

Reduced to Metallic

Iron



African Furnace Tall = Natural Draft Sauder & Williams Refractory with Blower



Physical Mechanism Messier!

Burning charcoal produces heat & C0



CHARCOKL AND ORE





Physical Mechanism Messier!

Burning charcoal produces heat & C0
Fe2O3 ore mixed with charcoal in top



CHARCOKL AND ORE





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CO removes oxygen, forms CO2





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Metallic iron particles, fall and sinter





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- Fe2O3 ore mixed with charcoal in top
- CO removes oxygen, forms CO2
- Metallic iron particles, fall and sinter
- Silica from ore & walls forms glass slag





MARKEWITZ

CHARCOKL AND ORE



Physical Mechanism Messier!

- Burning charcoal produces heat & C0
 - Fe2O3 ore mixed with charcoal in top
 - CO removes oxygen, forms CO2
 - Metallic iron particles, fall and sinter
- Silica from ore & walls forms glass slag
 - Bowl forms, solid at bottom, liquid inside





HARKEWITZ 204



Physical Mechanism Messier!

- Burning charcoal produces heat & C0
 - Fe2O3 ore mixed with charcoal in top
 - CO removes oxygen, forms CO2
 - Metallic iron particles, fall and sinter
- Silica from ore & walls forms glass slag
 - Bowl forms , solid at bottom, liquid inside
 - Iron bloom collects inside this slag bowl





LAD KERLADIT 2





Not so EASY! For any given Ore...

General shape & construction of furnace







- General shape & construction of furnace
- Combination of ore & charcoal size





- General shape & construction of furnace
- Combination of ore & charcoal size
- Height of reaction column







- General shape & construction of furnace
- Combination of ore & charcoal size
- Height of reaction column
- Volume / Pressure (!) air







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- Volume / Pressure (!) air
- Arrangement of tuyere







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- Arrangement of tuyere
- Ideal temperature range







- General shape & construction of furnace
- Combination of ore & charcoal size
- Height of reaction column
- Volume / Pressure (!) air
- Arrangement of tuyere
- Ideal temperature range
- Ideal addition rate for ore & fuel







Ore Varies!

• Fe00H / Fe2O3 / Fe3O4







Ore Varies!

- Fe00H / Fe2O3 / Fe3O4
- Fe Content







Ore Varies!

- Fe00H / Fe2O3 / Fe3O4
- Fe Content
- Density / Porosity







Ore Varies!

- Fe00H / Fe2O3 / Fe3O4
- Fe Content
- Density / Porosity
- Particle Size

Historically - Sites chosen for ORE







Designed for Bog Ore

Clay / Stone

Lodience, Bohemia







Designed for Bog Ore

- Clay / Stone
- ID : 30 50 cm

Lodience, Bohemia







Designed for Bog Ore

- Clay / Stone
- ID : 30 50 cm
- Height : 60 cm (?)

Lodience, Bohemia







Designed for Bog Ore

- Clay / Stone
- ID : 30 50 cm
- Height: 60 cm (?)
- Inset Tuyere @ 2.5 cm

Lodience, Bohemia







Designed for Bog Ore

- Clay / Stone
- ID : 30 50 cm
- Height: 60 cm (?)
- Inset Tuyere @ 2.5 cm
- Bottom Extraction (?)

Lodience, Bohemia

Earlangard, Norway

Remains Fragmentary = MUCH WAG





Historic Prototypes
Bloom Production





Very Few Artifacts!

Full Blooms





Historic Prototypes
Bloom Production





Very Few Artifacts!

- Full Blooms
- 5 10 kg range









Very Few Artifacts!

- Full Blooms
- 5 10 kg range
- Partially compacted









Very Few Artifacts!

- Full Blooms
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- Partially compacted
- Edge Cut









Very Few Artifacts!

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- 5 10 kg range
- Partially compacted
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Very Dense (5 - 6 gm/cc*)





Historic Prototypes ? High Volume Air Sauder & Williams



Proven System 1.2 - 1.5 l/m/cm2 (580 - 1270 l/m)





Historic Prototypes ? High Volume Air Sauder & Williams



Proven System 1.2 - 1.5 l/m/cm2 (580 - 1270 l/m)

Problems :

- Using electric blowers
- What is historic air?





Historic Prototypes ? Low Volume Air



Bloom from Margi, Africa

Passive or Small Bellows





Historic Prototypes ? Low Volume Air



Bloom from Margi, Africa

Passive or Small Bellows

Problems :

- Lacy consistency
- Reduced Yields







Hylestad, Norway

- Twin chambers
- Three lame construction
- Chamber 4 5 x hand width
- Tube from each chamber
- Chambers empty alternately







Hylestad, Norway

- Twin chambers
- Three lame construction
- Chamber 4 5 x hand width
- Tube from each chamber
- Chambers empty alternately

Problems:

- Artistic rendering
- Wood carving
- Impossible position







Ramsund, Sweden

- Twin chambers
- Width to length
- Proportion of inlet hole







Ramsund, Sweden

- Twin chambers
- Width to length
- Proportion of inlet hole

Problems :

- Simple outline
- Stone carving
- No scale





Historic Prototypes Viking Age Replicas ?



Bellows Reconstruction



Sand Table Forge

Smelting Furnace

Problem : 120 - 130 litres / minute BLACKSMITH'S Equipment!





Historic Prototypes 'Historical' Replicas ?



Nissen - Ribe, Denmark

Staffordshire, England

Olesen - Heltborg, Denmark

Double to Triple X Measurements Eight to Twenty Seven X Volumes

Function or Evidence ?





Historic Prototypes 'Historical' Replicas ?



Smelter Test Bellows

DARC - Canada, 2009

Green - USA, 2013

Theoretical Delivery = 750 l/m Measured Delivery = 350 l/m

Function or Evidence ?





Experimental Results Collecting Data

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50 + Experiments 48 + Variables





Experimental Results About the AIR (?)



Problem : Is BURN RATE more important?





Experimental Results About the AIR (?)







Experimental Results About the ORE (?)

Ore Fe to Yield



Problem : Small Fe change Is <u>type</u> important





Experimental Results About the ORE (?)

Ore Fe to Yield -Ore Fe % -Bloom kg Yield %

Problem : Small Fe change Is <u>type</u> important

Some direct effect





Experimental Results Experience Counts (?)



Problem : Changing Systems





Experimental Results Experience Counts (?)



Problem : Changing Systems

Maybe Not !









Oyane Norway

2006

BAR - not BLOOM





EXPERIMENT	VOLUME C litre/min	RATE kg/hour	Fe %	WEIGHT kg	BLOOM kg	YIELD %	DENSITY
36 / D15	7.2	11	54	20	1.9	10	4.3
9		10	65.0	21.3	9.5	45	4.4
32 / D14	4.1	7	54	18	2	11	4.6
8	8.15	634	57.5	28	7.5	27	4.7
22	10.6	15	57.5	18.8	6.8	36	5.2
41 / D19	9	9	61	20.7	5.6	27	5.5
13/ D7	6	15	60	19.7	4.3	22	5.6
24 / D11	9	12		20	0.9	5	5.7
D25	9	9	54	26	5	19	5.7
38 / D16	6.85	8		23	4.9	21	5.9
10 / D5	6	9	65.0	10.9	3	28	6.3
51 / D27	8	9	48	31.8	5.8	18	6.4 🕴
18 / D9	6	5		10.5			7.1
40 / D18	6.4	7	64	18	4.9	27	7.7
50	8	7		42.9	12.27	29	8.5
52	8	10		31.8	7.1	22	9.5

Increase in RATE = Improved **DENSITY** ?





EXPERIMENT	VOLUME C litre/min	RATE kg/hour	Fe %	WEIGHT kg	BLOOM kg	YIELD %	DENSITY	to BAR %
13/ D7	6	15	60	19.7	4.3	22	5.6	48
16	9.7	15	69	45.5	20	44		60
30		8	54	30.2	1.7	6		63
8	8.15		57.5	28	7.5	27	4.7	77
43 / D21	3.5		55	20	1.6	8		80
14	8	11		45.5	13.5	30		81
49	9	10	65.4	19.2	6.4	33		83

Increase in RATE = Improved <u>Bloom to Bar</u>?





EXPERIMENT	VOLUME C litre/min	RATE kg/hour	Fe %	WEIGHT kg	BLOOM kg	YIELD %	DENSITY	to BAR %
13/ D7	6	15	60	19.7	4.3	22	5.6	48
16	9.7	15	69	45.5	20	44		60
30		8	54	30.2	1.7	6		63
8	8.15		57.5	28	7.5	27	4.7	77
43 / D21	3.5		55	20	1.6	8		80
14	8	11		45.5	13.5	30		81
49	9	10	65.4	19.2	6.4	33		83

Increase in RATE = Improved <u>Bloom to Bar</u>? Inconclusive : Not Enough Data Points





Future Experiments Limit Variables! Furnace Design



Econo-Norse



Icelandic

- Material
- Dimensions
- Layout



Slag Pit





Future Experiments Limit Variables! Ore



Bratton's Run



Dark Dirt Analog

- Chemistry
- Concentration
- Form





Future Experiments Limit Variables! Bellows Design



Ubber-Bellows

Smelt Test Frame

Blower & 'Franken-bellows'

- Power
- Dimensions
- Operation





Future Experiments
Extend Process
Bloom to Bar





Vinland One - Compacting

Replica Currency Bar

- Develop Experience
- Historic Method
- Repeated Experiments





Further References The Adventure Continues !



the Wareham Forge www.warehamforge.ca/ironsmelting

> DARC www.darkcompany.ca/iron

