THE FUTURE (2020) HOT BLAST STOVES[1]

Cedric Colling [2]
Peter M. Martin [2]

Abstract:

This paper uses the trends that have emerged over the past few years to forecast the future development of stoves. Based on a typical current stove design we have forecast what improvements are realistically likely to occur in the next eleven years, particularly with respect to reducing heat losses and lowering emission levels. As the year 2020 is only eleven years into the future, and as this is a very conservative industry that traditionally prefers evolution to revolution, it would be very easy to forecast that the 2020 stove will be very much the same as it is today. However with ever increasing energy costs and the rapidly growing 'Green Lobby', both existing and new hot blast stoves are likely to be impacted by efforts to reduce energy consumption and to significantly lower emission levels.

Key words: Heat loss; Efficiency; Emissions; Environment.

O FUTURO DOS REGENERADORES

Resumo

Este artigo usa as tendências que emergiram nos últimos anos para prever os desenvolvimentos futuros dos regeneradores. Baseado no típico projeto de regenerador, nos previmos quais melhorias são realisticamente prováveis de ocorrer nos próximos 11 anos, particularmente com respeito á redução de perdas de calor e diminuição dos níveis de emissão. Como o ano de 2020 está á apenas 11 anos á frente, e como esta é uma indústria muito conservativa que tradicionalmente prefere evolução á revolução, seria muito fácil prever que em 2020 os regeneradores seriam muito parecidos com os de hoje. Contudo, com o constante aumento dos custos de energia e o rápido crescimento do 'Lobby verde', existentes e novos regeneradores serão impactados por esforços na redução do consumo de energia e para diminuir significativamente os níveis de emissão.

Palavras-chave: Perda de calor; Eficiência; Emissão; Ambiente.

---

[1] *Technical contribution to the 39th International Meeting on Ironmaking and 10th International Symposium on Iron Ore, November 22 – 26, 2009, Ouro Preto, MG, Brazil.*

[2] *Siemens VAI Metals Technologies Ltd, US Blast Furnace Principal Business Developer*

INTRODUCTION

Siemens VAI Metals Technologies, as a world leader in blast furnace stove design, is always trying to look at the future requirements for hot blast stoves. The purpose of this paper is to discuss some ideas that will shape the stove design and operation in the future.

INITIAL THOUGHTS ON HOW BLAST FURNACE OPERATING TRENDS WILL IMPACT HOT BLAST STOVE DESIGN

The future development of hot blast stoves is mostly always driven by two forces - the forever changing requirements of the blast furnace and the demands of the customer.

While alternatives to the blast furnace are available, and there are significant BF development programs underway, in the next 10-11 years we really don't see any massive changes to the blast furnace taking place.

We expect the following items to define future stove design efforts.

- Increase furnace productivity
- Increase in injection rates
- Higher blast temperatures

Individual customer priorities will vary but in general we think these items will be the key focus areas.

- Lower CAPEX
- Lower OPEX
- Longer stove life
- Higher hot blast temperatures
- Increased ability to utilize various fuels
- Lower emissions

While a major conceptual change in stove design is unlikely, the following significant changes are most likely to take place between now and 2020:

- New checker design enabling smaller checker chambers thus enabling lower CAPEX
- Multi-Fuel ceramic burners making the optimum use of mixtures of blast furnace gas, coke oven gas, natural gas and LD gas
- Ceramic burners suitable for combustion air with & without oxygen enrichment
- Ceramic burners with improved mixing & lower emissions
- Fully gas tight dividing walls, eliminating short circuiting and therefore reducing emissions
- Improved ring wall design to reduce shell energy loss
- Increased stress corrosion cracking protection to extend shell life
- Increased use of waste heat recovery and thus reduce energy consumption & emissions
- Continued implementation of stove oxygen enrichment systems

Most of the thin-wall chequers currently on the market are now about twenty years old and have too much mass and not enough heating surface area. Modern refractory pressing and firing techniques will now allow thinner walls to be used and improved gas cleaning plants will allow smaller flues without blockage occurring. For the user this will increase the specific heating surface area of a typical chequer by approximately 20% and more importantly reduce the checker mass required by around 10%.

With increasing energy costs affecting all ironworks, more imagination and flexibility is required in the use of various available gases at the hot blast stoves. A multi fuel burner is therefore required to take full advantage of whatever fuels are available. Similarly a burner designed for conventional operation needs to be able to satisfactorily make use of oxygen enriched combustion air when economical excess oxygen is available.

The dividing wall design on internal combustion chamber stoves is continuing to improve with various solutions available varying from walls incorporating metallic membranes to ceramic panels, but can still only be considered to be a gas barrier and not fully gas proof. No-one has yet fully solved this dividing wall problem and this may be partly why CO emissions from external combustion chamber stoves are generally lower than for the internal combustion chamber stoves, even when using similar burners.

A one hundred per cent solution to the stress corrosion cracking problem still remains elusive after first appearing in the late 1960's. As hot blast temperatures and dome temperatures are both likely to increase in the near future, there is likely to be some pressure to overcome this problem more convincingly than some of the recent 'solutions' which at best buy time.

Waste heat recovery, accompanied with gas and combustion air preheating is becoming an essential part of a stoves installation due to the significant energy recovery.

Stove oxygen enrichment systems, which reduce enrichment gas consumption at a low CAPEX, will continue to grow.

FURNACE STOVE OPERATION TRENDS

Based on future Blast Furnace trends and customer requirements, by 2020 the typical stove operation will include:

- A Blast Temperature Between 1200ºC & 1275ºC (2192-2327ºF)
- A Maximum Dome Temperature of Between 1350ºC & 1450ºC (2462-2642ºF)
- A Maximum Flue Gas Temperature of 400ºC (752ºF)
- Gas & Air Preheat Temperatures Between 160ºC (320ºF) & 180ºC (356ºF)

It may be noted that some recent customer studies have shown Stove Hot Blast Temperature may be limited not just by stove material limits but also the stove enrichment gas cost and overall BF economics from higher HBT operation. This maximum economic HBT will be site specific

Internal Combustion Chamber Stoves

External Combustion Chamber Stoves

Shaftless Stoves

Figure 1: Current hot blast stoves technology.

Available current stove technology comprises internal combustion chamber stoves, external combustion chamber stoves and shaft-less stoves. All of these designs depend upon a burner, or burners, a combustion chamber and a chequer chamber and it is difficult to envisage any conceptual change from this in the next 10 years.

Modern versions of these designs all have relatively low heat losses from their well insulated shells but unavoidably high losses in the flue gases. They also now all have relatively low emissions, but none yet achieve the legislative levels of most countries. There is therefore still room for improvement in reducing heat losses and emissions.

The above is what we can expect from new stoves. However there is a much greater problem than the new stove and that is the older stove. Stoves realistically last forty years or more and therefore there are many stoves operating today which were designed without either energy loss or emission levels in mind. Also it is not uncommon for these stoves to be rebuilt on a ‘like for like’ basis, which then continues the energy loss and emission problems for at least another ten to fifteen years.

ENERGY & ENVIRONMENTAL ANALYSIS

In order to demonstrate the scale of energy losses and emissions from hot blast stoves, a typical set of three stoves operating at a medium duty level was modelled. We adopted a blast volume of 250,000 Nm³/h plus 5% oxygen enrichment and 30 g/Nm³ blast moisture, delivered to the furnace at a temperature of 1200ºC.

Straight Line Blast Temperature	1200ºC (2192ºF)
Total Blast Volume	274,323.3 Nm³/h (171,806.4 SCFM)
Increase In Percentage O2	5%
Moisture Content of Final Blast	30 g/Nm³ (13.2 gr/SCF)
Mode of Operation	3 Stove Cyclic

Blast Period	45 Minutes
Maximum Dome Temperature	1350ºC (2462ºF)
Maximum Flue Gas Temperature	400ºC (752ºF)
Mixed Gas Calorific Value	1131 kCal/Nm³ (119.5 BTU/SCF)
Stove Heating Surface Area	52,400 m² (564,000 ft²)
Approx. Chequer Mass per Stove	1630 tonnes (1800 US tons)

Based on the assumed operating data, the heat gains and losses can be calculated for a conventional three stove system(table 1).

Table 1: Daily thermal gains & losses to and from three stoves

	GJ	BTU	% Heat Distribution
Total Thermal Input	13,211	12.52×10^9	100.00
Heat Losses from Stove Shells	422	0.40×10^9	*3.19*
Heat Losses from Hot Blast Main	314	0.30×10^9	*2.38*
Heat Losses to Stack	2,356	2.23×10^9	*17.83*
Total Losses per Day	3,092	2.93×10^9	*23.40*
Total Heat Gain by Blast	10,119	9.59×10^9	*76.60*

Using the output from the model it was forecast that to achieve a medium blast duty of 250,000 Nm³/h at a blast temperature of 1200ºC, a daily input to the stoves of 13,211 GJ will be required, which is a significant amount of energy. This is distributed as follows:

Heat loss from the stove shells is forecast at 422 GJ/day or just over 3% of the total energy consumption. This can obviously be reduced, but at a cost. Possible items are as follows:

- Increased insulation in the ring walls will reduce this loss, but this will increase capital cost and in some cases reduce stove performance.
- For a new stove it will mean the additional cost of an increased shell diameter and the cost of the extra insulation.
- In the case of a rebuild inside an existing shell there is the cost of the extra insulation, plus a loss of the effective volume of the stove, reducing the volumes of the combustion chamber and the chequer chamber with a corresponding loss of performance.

Heat loss from the hot blast main is forecast at 314 GJ/day or just over 2% of the total energy consumption. This can also reduced, but at a cost for extra insulation and possibly a loss in capacity or performance.

With a 400ºC maximum flue gas temperature the stack losses account for 2,356 GJ/day which is almost 18% of the thermal input. In order to reduce this significant loss, we initially examined the effect of waste heat recovery.

Daily Thermal Inputs & Outputs for a Typical 2009 Three Stove System with Waste Heat Recovery

Based on the previously specified duty, the following are the calculated heat gains and losses for a conventional three stove system when operating with waste heat recovery and gas and air preheated to 180ºC (356ºF).

Daily Thermal Gains & Losses To & From Three Stoves

Table 2: Daily thermal gains & losses to & from three stoves with waste heat recovery

	GJ	BTU	% Heat Distribution
Total Thermal Input	11,908	11.29×10^9	100.00
Heat Losses from Stove Shells	380	0.36×10^9	*3.19*
Heat Losses from Hot Blast Main	314	0.30×10^9	*2.64*
Heat Losses to Stack	1,095	1.04×10^9	*9.19*
Total Losses per Day	1,789	1.70×10^9	*15.02*
Total Heat Gain by Blast to Furnace	10,119	9.59×10^9	*84.98*

By installing waste heat recovery the gas and the combustion air can each be preheated to a mean temperature of 180ºC.

- This reduces the heat loss to the stack to 1,095 GJ/day, which is less than 50% of the stack losses in the original case.
- Overall stove thermal efficiency improved by approximately 10%.

Further improvement in the heat loss up the stack is difficult because designs need to stay above the acid dew point of the flue gas so cannot remove any more heat in the pre-heaters.

EFFECT OF INCREASED HEATING SURFACE AREA ON HEAT LOSS

The installation of a waste heat recovery and preheat system appears to be a very attractive proposition, both in terms of energy savings and in the reduction of expensive enrichment gases. However its capital cost is high and from experience it is known to be a high maintenance system with considerable down time. Therefore as a more maintenance free alternative to waste heat recovery, the effect of increasing the size of the stove was examined.

The base case stove size used for the earlier waste heat recovery cases had a heating surface area of 52,400 m². With waste heat recovery this stove loses 1,095 GJ/day to the stack. To achieve this, or lower, we would have to more than double the heating surface area. This would greatly increase CAPEX and may not be feasible for rebuilds due to footprint limitations. This maintenance free option is therefore not a realistic alternative solution in most cases.

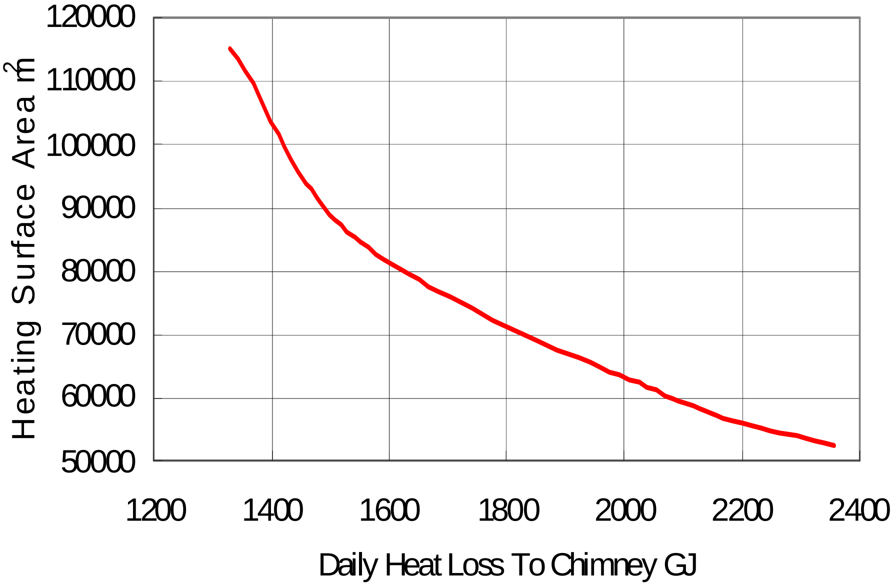

Figure 2: Heating surface area X daily heat loss to chimney GJ.

CONCLUSIONS REGARDING ENERGY CONSUMPTION

By installing a waste heat recovery system and increasing the insulation in the stoves and hot blast main linings, it should be comfortably possible to reduce energy consumption by ten per cent on many plants.

COMBUSTION IN A SIEMENS VAI STOVE

A combustion analysis was done is for the same stove design used for the previous energy calculations. The combustion analysis provides data on emissions. Combustion with both coke oven and natural gas enrichment is considered.
Dry gas analyses by % volume:

Blast Furnace Gas		***Coke Oven Gas***		***Natural Gas***	
CO	21.5 %	CO	5.0 %	CO_2	1.4 %
CO_2	22.5 %	CO_2	1.0 %	N_2	3.2 %
H_2	3.5 %	H_2	59.0 %	CH_4	89.0 %
N_2	52.5 %	N_2	3.85 %	C_2H_6	5.0 %
		CH_4	27.0 %	C_3H_8	1.4 %
		C_2H_6	4.0 %		
		H_2S	0.15 %		

Flame temperature: 1400ºC (2552ºF)
Required enrichment: COG: 10.9 % NG: 6.3 %
Assumed excess air = 10%.

The enrichment gas percentage is slightly different to the previous analysis as in this combustion calculation we looked particularly at a coke oven gas analysis which included H_2S to calculate the amount of SOx produced.

EMISSIONS

Stove emissions depend on many different factors e.g. the type of burner and stove combustion efficiency.

Typical ranges for Hot Blast Stoves are:

External Combustion Chamber		***Internal Combustion Chamber***	
CO	100 – 500 ppm	CO	500 – 1000 ppm
NO_X	< 50 ppm	NO_X	< 50 ppm

The use of Waste Heat Recovery or Natural Gas as opposed to Coke Oven Gas can also have an effect:

With WHR:	SOx reduced by 54%	With NG:	SOx reduced by 100%
	CO reduced by 18%		CO reduced by 9%
	CO_2 reduced by 10%		NOx reduced by 4%

The previous reflects the experience that external combustion chamber stoves exhibit lower CO emissions.

NG is a much cleaner gas with effectively no sulfur but is also more expensive. COG is often produced on the plant so is readily available and cheap.

WHR, in addition to reducing the energy consumption, reduces the amount of SOx and NOx produced in the flue gas. It also has a positive effect on reducing CO and CO_2 production.

NG, which doesn't reduce stove energy consumption levels compared to COG but does reduce the SOx completely.

INFLUENCE OF STOVE DESIGN

Internal Combustion Chamber Stoves

The major emission issues with the internal combustion chamber stove are as follows:

- Dividing wall - Potential for gas tracking causing uncombusted gas to pass straight into the flue
- Combustion Chamber - Size and shape of chamber could affect combustion efficiency
- Type of Burner - Type of burner can affect combustion efficiency

Figure 3: Internal Combustion Chamber Stove

External Combustion Chamber Stoves

Here are the environmental implications for the external combustion chamber stove. These items can also generally apply to the shaft less stove design. This design obviously has a much larger footprint which can particularly impact existing blast furnace plants.

- No dividing wall so no gas tracking
- Higher dome temperatures – able to meet future demands of the blast furnace
- Suitable for large heating surface areas so capable of higher blast volumes – able to meet future demands of the blast furnace

Figure 4: External combustion chamber stove.

COMBUSTION EFFICIENCY

The emission related issues regarding burner design items are discussed in this section.

Ceramic burners are more efficient but currently have larger turndown issues which become an issue with stove oxygen enrichment system applications.

Types of Burner

- Metallic - which tend to have higher emissions due to poor mixing and un-burnt gas tracking through a flame impingement damaged dividing wall.
- Ceramic - which are suitable for pre-heated gas and air, which fits in with future trends of the use of waste heat recovery, and have a higher combustion efficiency with lower emissions.

Future aims would be to improve combustion efficiency by improving mixing via modifying and improving burner and dividing wall designs

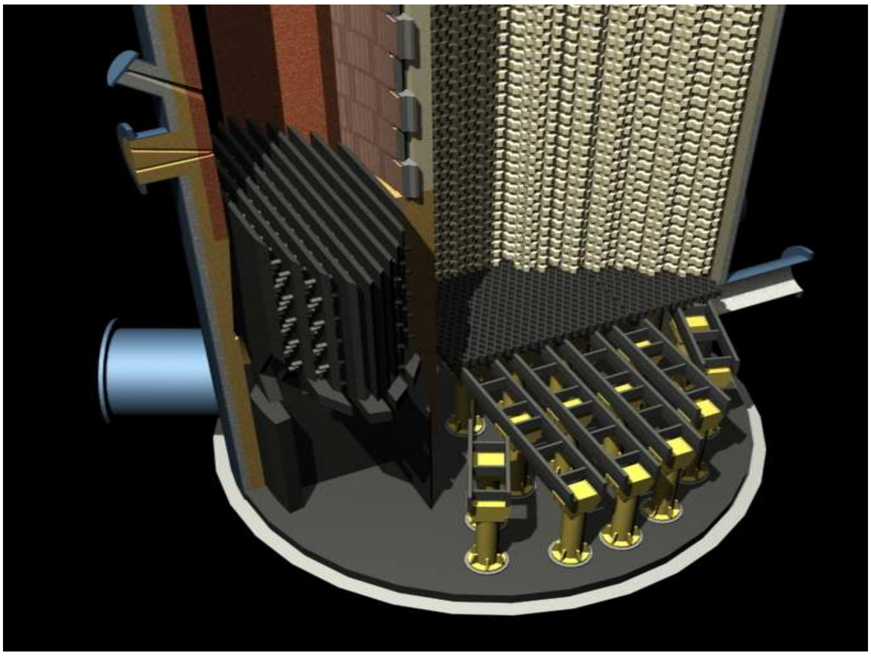

Figure 5: Stove-Internal view.

Automation and Instrumentation

Combustion efficiency can be improved by the following:

- Enrichment gas trimming
- Early detection of deviations and deteriorated combustion
- Continuous analysis of flue gas

A small change in combustion efficiency makes a big difference in percentage of CO in the flue gas. Even a small improvement in combustion efficiency can drastically reduce the CO emissions of the hot blast stove

Combustion efficiency, and emission performance, can be improved with improved automation systems

The gains here impact the emission performance much more than the overall stove energy balance.

CO_2 Emissions

Although classed as an emission CO_2 is actually the main product of combustion in the hot blast stoves. The quantities of CO_2 therefore are much larger than the other emission components, these are summarised below:

		ppm	mg/m3 (gr/SCF)
Coke Oven Gas	CO_2	240,116	471,738 (195.4)
Natural Gas	CO_2	239,265	470,067 (194.7)

These calculated CO_2 values are based on 10% excess air and 99.95% combustion efficiency.

The total CO_2 production from the typical three stove system is more than 1 million tonnes/year

With levels in the 24-25% range in the exhaust gas, CO_2 emissions from a stove are significant with a 1:1 ratio to iron production.

Most of the fuel used in the stoves is blast furnace gas. If not used here would either be flared or used elsewhere so recycling blast furnace gas in fact reduces CO_2 emissions from the overall plant. The combustion efficiency of a flare stack can range from 65 to 100% so using the blast furnace gas in the stoves will produce less CO_2 than if the gas were to be flared. To be able to further reduce CO_2 emissions, the reduction can only come from the enrichment gas which is added to the blast furnace gas. Stove oxygen enrichment can play a major role here.

RECENT GLOBAL DRIVE TO REDUCE EMISSIONS

Recent environmental legislation acts has pushed the need to reduce CO_2 levels. The major ones are:

- U.S. Environmental Protection Agency (EPA) recently announce plans to reduce emissions by 14% by 2020 and 83% by 2050
- E.U. has given final approval this spring to reduce greenhouse gases by 20% of 1990 levels by 2020

In the US the EPA will be monitoring all companies producing > 25,000 tonnes (27,600 tons) of CO_2 equivalent per year

CONCLUSION

The 2020 stove design will include several key components.

The designs will be aimed at reducing CAPEX/OPEX, increased hot blast temperatures and providing longer campaign lives.

Designs will be aimed at improving energy efficiency by developing improved checker designs, reducing the heat losses to atmosphere, utilizing waste heat recovery to reduce stack losses by approximately 50%, utilizing various fuels and incorporating stove oxygen enrichment systems.

Designs will also focus on reducing emissions. Items will include using cleaner (and less) enrichment gas, utilizing external or improved internal combustion chamber stoves, developing more efficient burners and further automation applications to improve stove performance.

Acknowledgements

The authors wish to acknowledge the help and support of their colleagues at Siemens VAI for the valued contribution to the final edited version of this paper.