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IMPROVED BLAST FURNACE STOVE OPERATION WITH THE USE OF OXYGEN ENRICHED COMBUSTION AIR[1]

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Abstract

The operation of the Blast Furnace as a means of primary iron production continues to develop in response to the requirements of reducing overall cost and coke consumption. The B.F. operation has changed with the demand for higher blast temperatures from the Stoves plant; the increased duty for the Stoves plant has resulted in the heating cycle fuel gas being supplemented with a high calorific value gas increasing the operating cost. The phenomenon of increasing the oxygen content of ambient air to achieve an increase in the temperature of combusted fuel gasses is understood and practiced in other applications. The technology is beginning to be applied to the combustion process in the stoves heating cycle so as to provide a number of benefits: reduce or eliminate enrichment fuel gas; reduce the flue (waste) gas flow; maintain or increase the hot blast temperature. The paper will explore the implementation of this technology on an operating furnace incorporating three internal stoves, with the resultant changes in blast conditions and fuel gas consumption. A brief review of future developments in the field is incorporated.

Key words: Stoves; Oxygen enrichment; Fuel combustion; Flame temperature.

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1 INTRODUCTION

The operation of the Blast Furnace as a means of primary iron production continues to develop in response to the requirements of reducing overall cost and coke consumption. The B.F. operation has changed with the demand for higher blast temperatures from the Stoves plant; the increased duty for the Stoves plant has resulted in the heating cycle fuel gas being supplemented with a high calorific value gas increasing the operating cost.
The phenomenon of increasing the oxygen content of ambient air to achieve an increase in the temperature of combusted fuel gasses is understood and practiced in other applications. The technology is beginning to be applied to the combustion process in the stoves heating cycle so as to provide a number of benefits:

- Reduce or eliminate enrichment fuel gas.
- Reduce the flue (waste) gas flow.
- Maintain or increase the hot blast temperature.

The paper will explore the implementation of this technology on an operating furnace incorporating three internal stoves, with the resultant changes in blast conditions and fuel gas consumption. A brief review of future developments in the field is incorporated.

2 DISCUSSION

Siemens VAI had previous North American successes utilising oxygen enriched air in stove firing to eliminate enrichment gas while maintaining or increasing the resultant hot blast temperature. These installations had also shown the ability to increase stove heat input rates and hot blast temperature further when deteriorated stove conditions limit the amount of combustion air that can be utilised.
The concept of utilising oxygen enriched air for stoves heating was introduced to FNsteel by Linde Gas AGA during 2010 culminating in the project commencing in December 2010. FNsteel's primary objectives for the project included the elimination of propane enrichment of the stoves heating fuel gas and improved stove operation represented by the blast duty of flow and temperature. FNsteel also stipulated that the stove operation should maintain the ability to utilise propane enrichment if the performance with oxygen enriched air failed to meet the blast duty.
FNsteel have instigated other projects for the blast furnace at Koverhar including furnace repairs and modifications for summer 2012, phased stove repairs for October 2011 to March 2012, and replacement of the gas cleaning plant in 2009. With the adoption of stoves oxygen enrichment FNsteel were hoping to maintain the blast duty utilising a two stove operation for which results are presented below. The oxygen enriched stove heating operation with the new gas cleaning plant (a wet variable area venturi scrubber) will be demonstrated during 2012, i.e. after the furnace modifications.
The benefit to the stove heating cycle from utilising oxygen enriched air has two main components due to the nature of the combustion process:

- The adiabatic flame temperature will rise, for a given fuel gas calorific value.
- The radiative heat transfer from the combusted gases to the stoves refractory will increase, due to the replacement of nitrogen in the air.

A secondary benefit to oxygen enriched air should be a reduction in the combusted (waste) gas volume due to the changed combustion air/fuel ratio, for a fixed heat demand of the stove.

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3 MODELLING STOVE PERFORMANCE

During the project execution numerous modelling of the expected stove performance was conducted by Siemens-VAI, Linde Gas AGA and others so as to provide FNsteel with predictions for the required oxygen enrichment in replacing the use of propane. The charts included below indicate the parameters for the oxygen enrichment with varying furnace top gas calorific values defined by the hydrogen concentration.

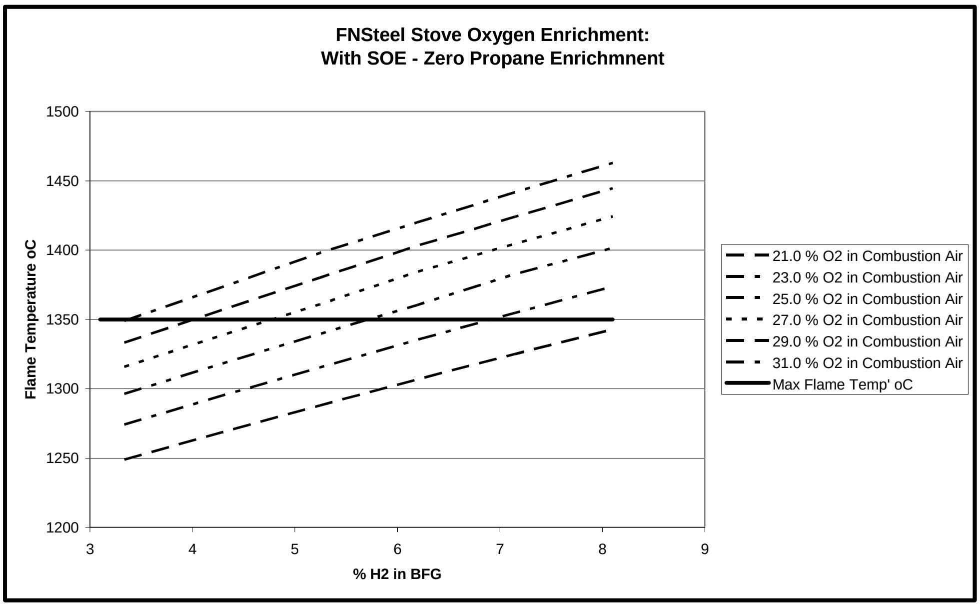

Figure 1. BFG C.V. .v. Flame Temperature for Varying Oxygen in Air Concentration.

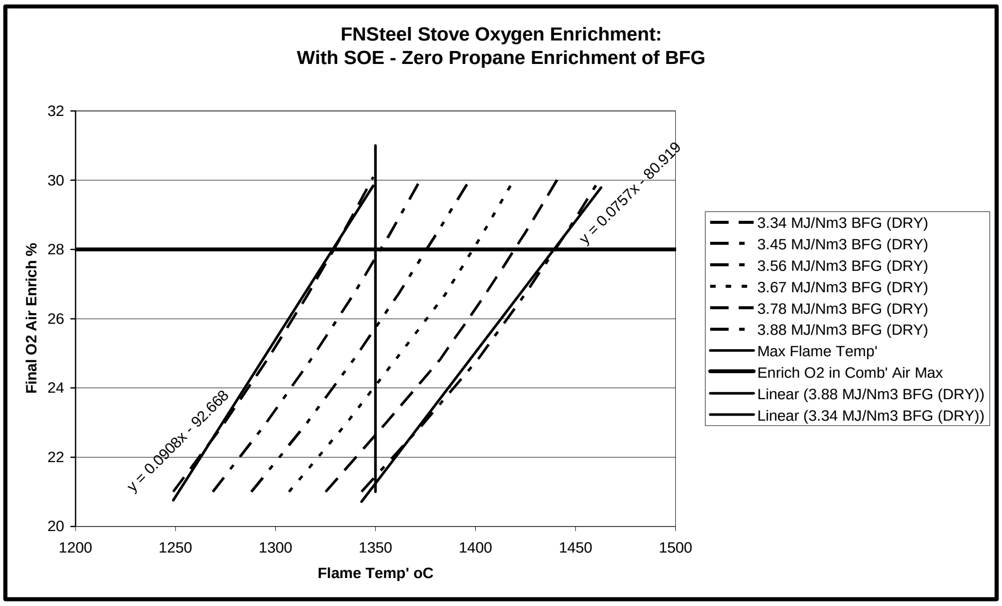

Figure 2. Flame Temperature .v. Oxygen in Air Concentration for Varying BFG C.V.

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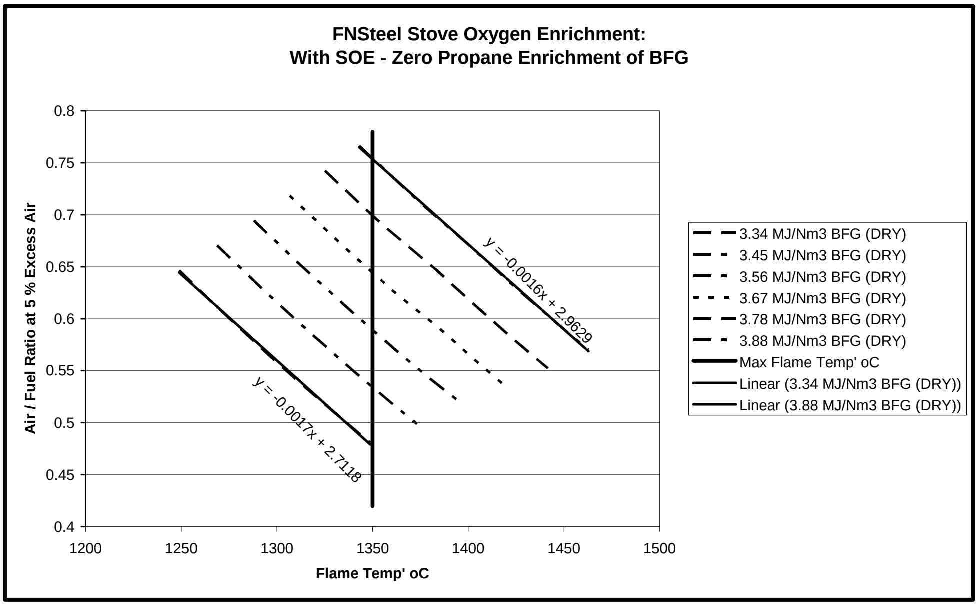

Figure 3. Flame Temperature .v. Air/Fuel Ratio for Varying BFG C.V.

The charts indicate that the modelling predicts a three stove cyclic operation with a flame temperature of 1350°C was possible. The maximum allowable oxygen in air concentration of 28 % could provide the required flame temperature with blast furnace gas calorific values in excess of 3.45 MJ/Nm^3.
The charts included below indicate the parameters for propane enrichment of the furnace top gas for the required flame temperature.

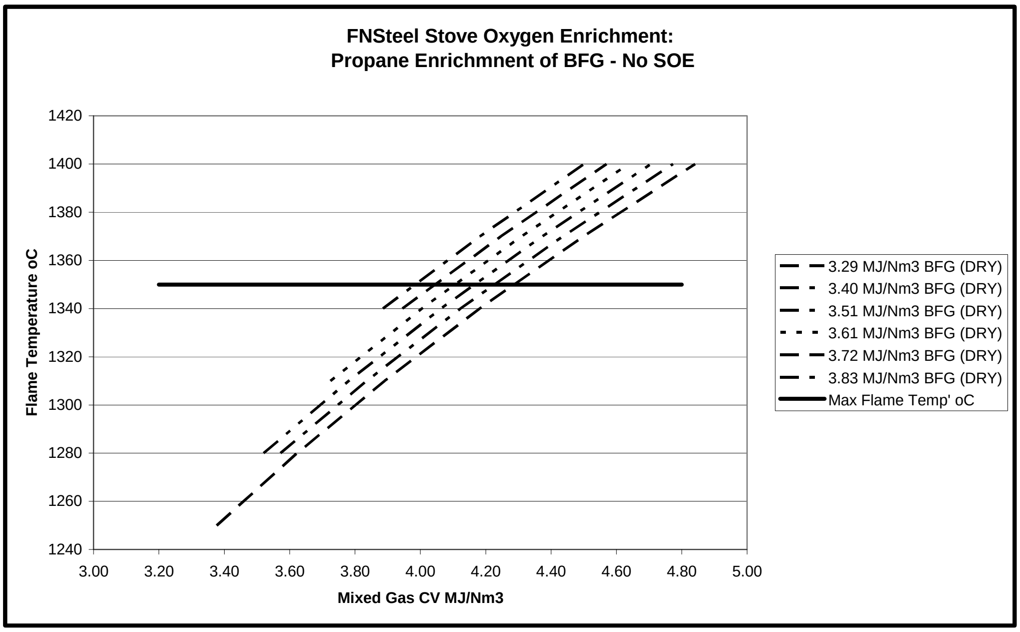

Figure 4. Mixed Gas C.V. .v. Flame Temperature for Varying BFG C.V.

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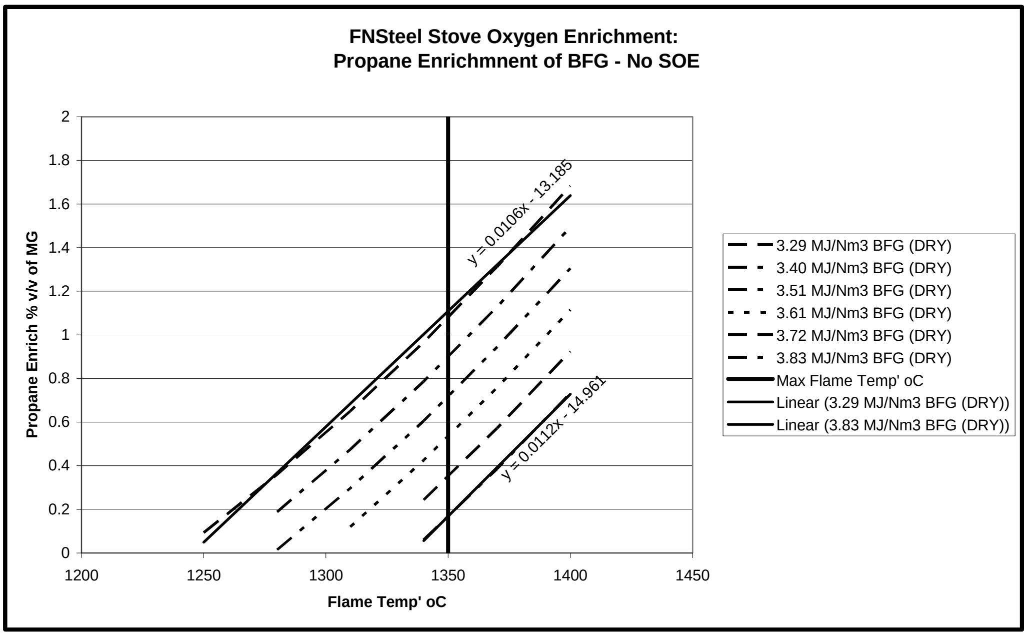

Figure 5. Flame Temperature .v. Propane Concentration in Mixed Gas for Varying BFG C.V.

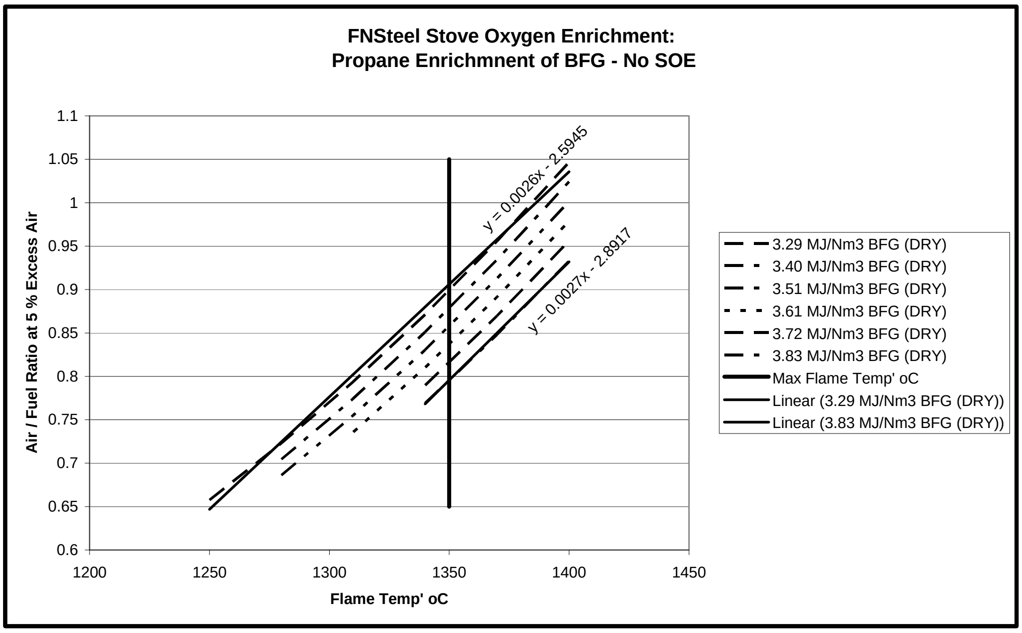

Figure 6. Flame Temperature .v. Air/Fuel Ratio for Varying BFG C.V.

The charts indicate that for a rich furnace top gas the stove operation would not require propane enrichment of the fuel gas.

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4 FLOW SHEETS

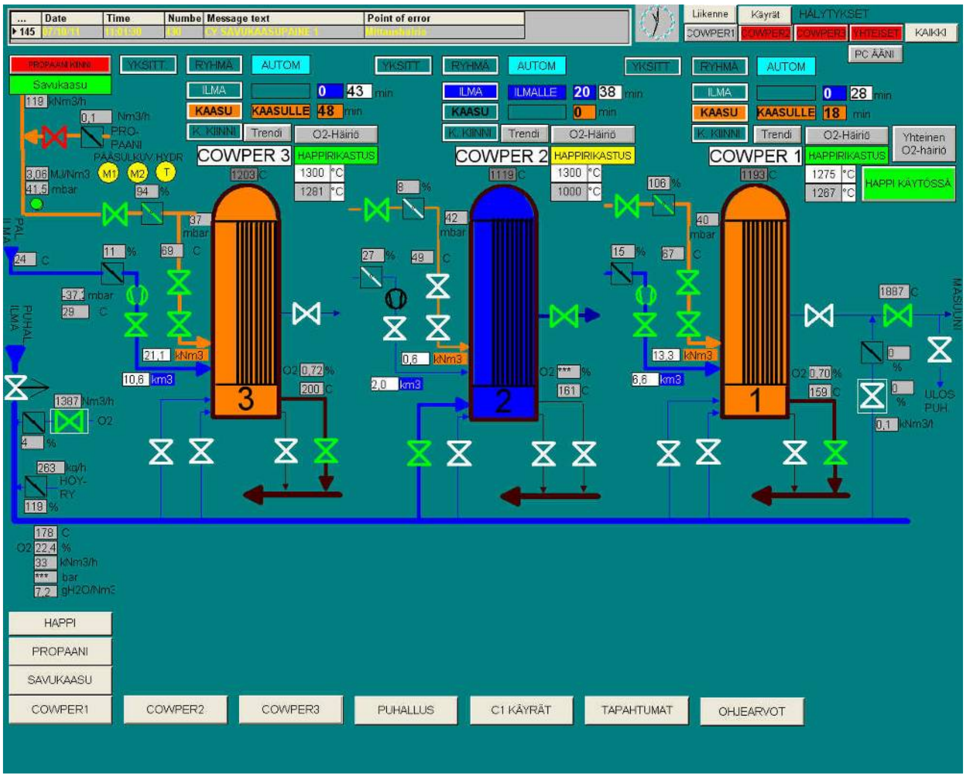

Figura 7. Existing stoves flow sheet with common fuel gas enrichment.

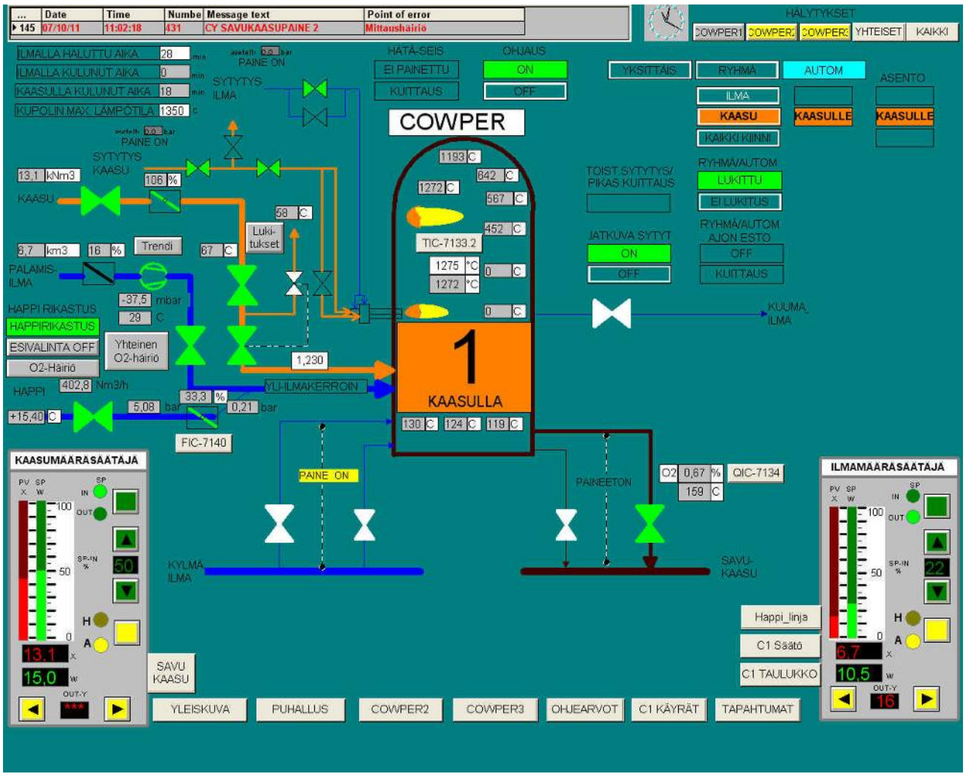

Figura 8. Stove with Oxygen Addition to the Combustion Air.

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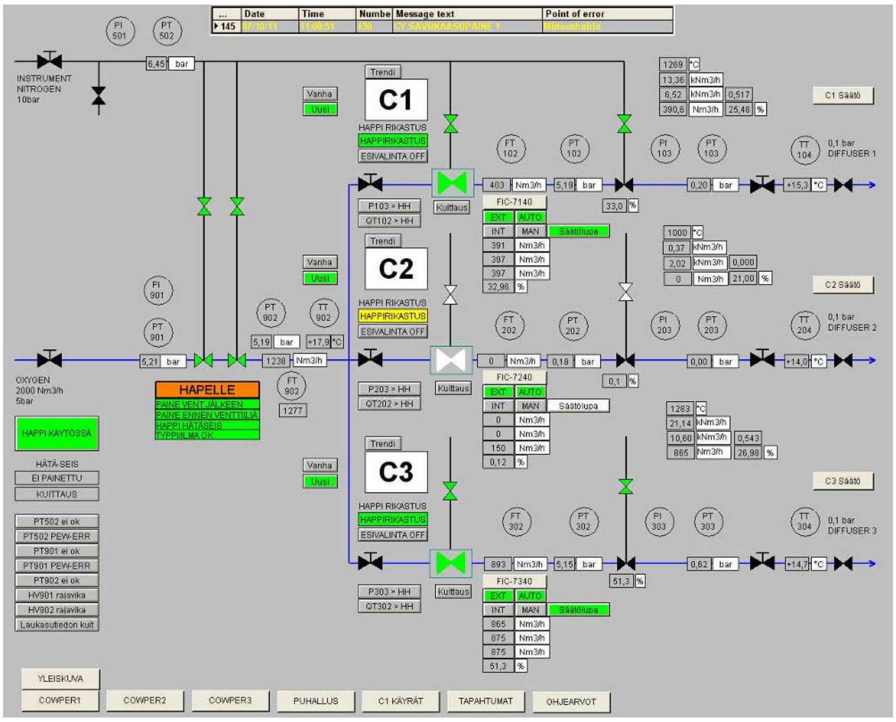

Figure 9. Oxygen Flow Control Valve Train.

5 PROPANE ENRICHMENT CONTROL

The propane enrichment of blast furnace gas can be controlled either as constant mixed gas calorific value or constant enrichment flow. The stoves control system is responsible for the control of the propane enrichment flow being fed to the mixed fuel gas header main and for the individual mixed fuel gas flow to each stove. The mixed fuel gas combines with the combustion air at the top of the ceramic burner and is ignited in the stove combustion chamber, though the burner arrangement allows a portion of the mixed fuel gas to enter the combustion air stream within the burner refractory arrangement.

The propane enrichment flow control consists of three stages:

- Pressure control valves of a mechanical-spring type to maintain a constant pressure in the propane enrichment flow prior to mixing with blast furnace gas.
- Flow control valve pneumatically operated with the set-point derived by the operator or a level 2 control program.
- Safety shut-off valves, fail close electro-magnetic operation, with the ‘propane enrichment’ command from the control system providing the open signal.

6 OXYGEN ENRICHMENT CONTROL

For the oxygen enrichment of combustion air the oxygen is controlled as an individual flow to each stove, i.e. there are three sets of oxygen flow control and safety shut-off valves. The stoves control system is responsible for the control of the ambient air flow and oxygen enrichment flow to each individual stove, with the oxygen being mixed in to the ambient air, via proprietary diffuser, in the combustion air branch between the combustion air shut-off valve and the stove shell. For the provision of ambient air each stove has an individual variable voltage – variable frequency electrically driven fan with the ambient air flow modulated by a fan inlet valve.

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The oxygen enrichment flow control consists of three stages:

- Isolation control valves sited in the supply header, pneumatically operated, with the open signal provided by an oxygen enrichment command entered by the operator.
- Flow control valves pneumatically operated, one per stove, with the set point derived by the stoves control program.
- Safety shut-off valves pneumatically operated, one per stove, with the open command derived from the operator selecting the individual stove to 'oxygen enrichment'. To provide safety within the control system the open command is removed for deviation in the oxygen supply pressure, high oxygen pressure at the diffuser, very high flow to the individual stove, or valve position limits being generated simultaneously.

With the control system healthy and oxygen enrichment selected for the individual stoves the set points for the oxygen flow control valves are enabled and modified by the stoves control system. To enable the oxygen flow control to an individual stove a number of pre-conditions have to be satisfied: ambient air flow at or above a minimum, fuel gas flow at or above a minimum set point, and the flame established with a time period, thereby signifying the stove is 'On-Gas'. The set point for the individual oxygen enrichment flow controllers is determined from "Look-Up Tables" for the combustion air oxygen concentration, populated from the chart above. The determination of the oxygen concentration requires the provision of two inputs: the flame or dome temperature set point by the operator and the blast furnace gas calorific value as an on-line measurement or operator input.
With the fuel (blast furnace) gas flow at the minimum set point the combustion air / fuel gas ratio changes to reflect the requirements of oxygen enriched air. The oxygen enriched combustion air / fuel gas ratio set point is determined from "Look-Up Tables", populated from the chart above. Similar to the combustion air oxygen concentration the determination of the oxygen enriched combustion air / fuel gas ratio requires the provision of the two inputs of flame or dome temperature and blast furnace gas calorific value.

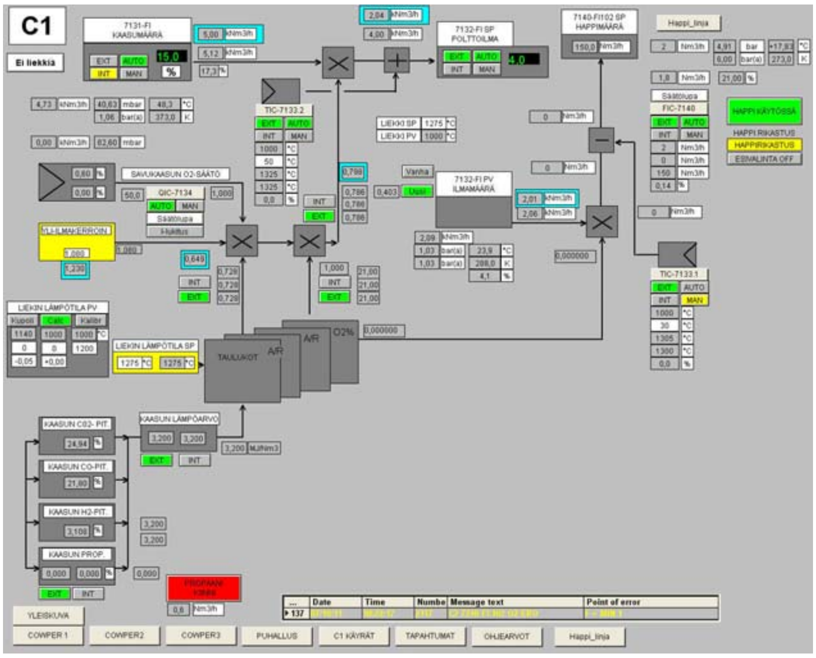

Figure 10. Schematic of an overview of the control logic for determining the stove oxygen enrichment set points.

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7 STOVES PERFORMANCE DATA

The charts included below are HMI screen shots from the commissioning of the stoves oxygen enrichment during October 07th 2011. During the commissioning period of October 04th to 07th the stoves operation reverted to propane enrichment during the night shift and oxygen enrichment testing in manual, semi-auto and automatic modes during the day shifts. The control of the oxygen flow for oxygen enrichment was tuned to allow for the differing measured furnace top gas conditions of calorific value and temperature resulting in the expected performance as modelled by Siemens-VAI agreeing with that modelled by FNsteel. For interpretation of the HMI screens the following translations are provided:

- Liekki t = Flame temperature
- Polttokaasun virtaus / Kaasuvirtaus = BFG flow
- Polttoilman virtaus / Palamisilma = Ambient (Combustion) air flow
- Hapen virtaus / Happivirtaus = Oxygen flow
- Kaasun paine = BFG pressure
- Savukaasu O2 = Waste (Flue) Gas Oxygen %

Figure 11. Stove 1 Operating Data Oct' 07th 2011 07:19 hrs to 11:19 hrs a.m.

Note: the elevated flame temperature during propane enrichment gassing due to the stoves operation being based upon a fixed propane flow.

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Figure 12. Stove 2 Operating Data Oct' 07th 2011 07:19 hrs to 11:19 hrs a.m.

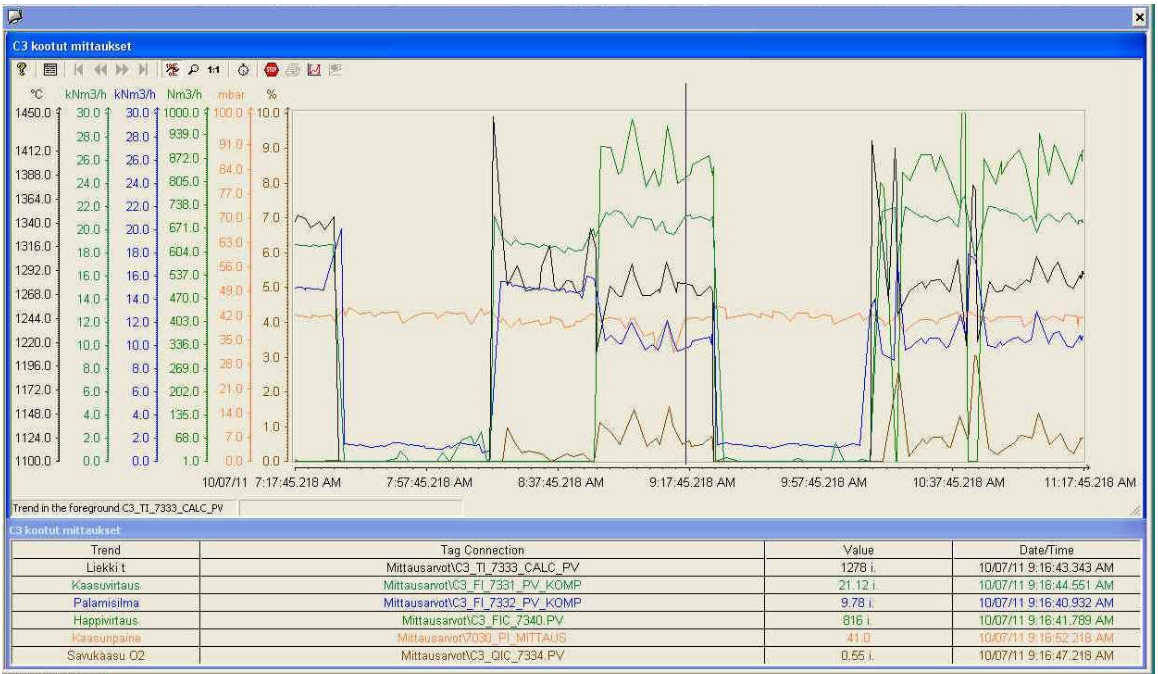

Figure 13. Stove 3 Operating Data Oct' 07th 2011 07:17 hrs to 11:17 hrs a.m.

For the manual and semi-auto commissioning of the oxygen enrichment of the combustion air flow the stoves dome temperatures were maintained at the levels achieved for propane enrichment in the previous shift.

From the HMI trends above certain stoves operating criteria are apparent:

- The flame temperature is maintained when the operation is changed from propane to oxygen enrichment.
- For stove oxygen enrichment the mixed gas (solely blast furnace gas) flow increases and the ambient air flow decreases, as predicted by the modelling.

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For the final commissioning test of the stoves in oxygen enrichment automatic mode conducted on October 07th 2011 the stoves blast duty was maintained at:

- Stove No.1 – blast period of 28 minutes, flame temperature of 1275 °C.
- Stove No.2 – blast period of 38 minutes, flame temperature of 1300 °C
- Stove No.3 – blast period of 43 minutes, flame temperature of 1300 °C

8 SUMMARY

Since October 2011 the stoves plant at FNsteel, Koverhar has been operating in two stove cyclic mode whilst the stoves have been repaired in a phased manner. For the two stove operation the blast duty has been maintained with the oxygen enrichment levels increased to 32% O_2 in the combustion air.
The oxygen enrichment system has not been optimized during this period and operation in a three stove cyclic mode will not occur until autumn 2012. For this reason the initial operating data over repeating stove cycles is not available, though FNsteel, Linde Gas AGA and Siemens-VAI expect the future operation to meet expectations. This information will be shared in a future paper.

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