ACCUSTEEL LTD.

S/D Engineers, Inc.

Real Time Acoustic Technology for Steelmaking

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Accusteel Real Time Melter Control System

- An electric steelmaker's dream to see what's going on inside the furnace during melting has finally became a reality.
- Besides listening to the sound of the furnace, he can now see on a computer display the development of liquid phase (both liquid steel and slag), monitor and control the behavior of foamy slag, observe and control energy utilization - all in real-time throughout the entire heat.
- At any time the data from every heat can be analyzed and visualized with the Data Analyzer Program, which archives the data from all heats.
- Today, this technological breakthrough is possible with the Accusteel Real Time Melter Control System (Accusteel RTM) - a real-time computer monitoring system for the electric arc furnace steelmaking process.

System Physical Principle

- The system is based on a non-contact acoustical method of detecting the key parameters of the steelmaking process, derived in real time from sound waves ("noise") generated in the process of melting scrap in EAF.
- Accusteel System measures the thermodynamic temperature based on an empirical correlation between temperature, acoustic noise frequency and an operating parameter of the furnace.

$$T = \frac{(LF)^2}{KR}$$

- L – wavelength of acoustic signal (~ power consumption of the furnace)
- F – frequency of acoustic signal
- K, R – gas constants (CO)

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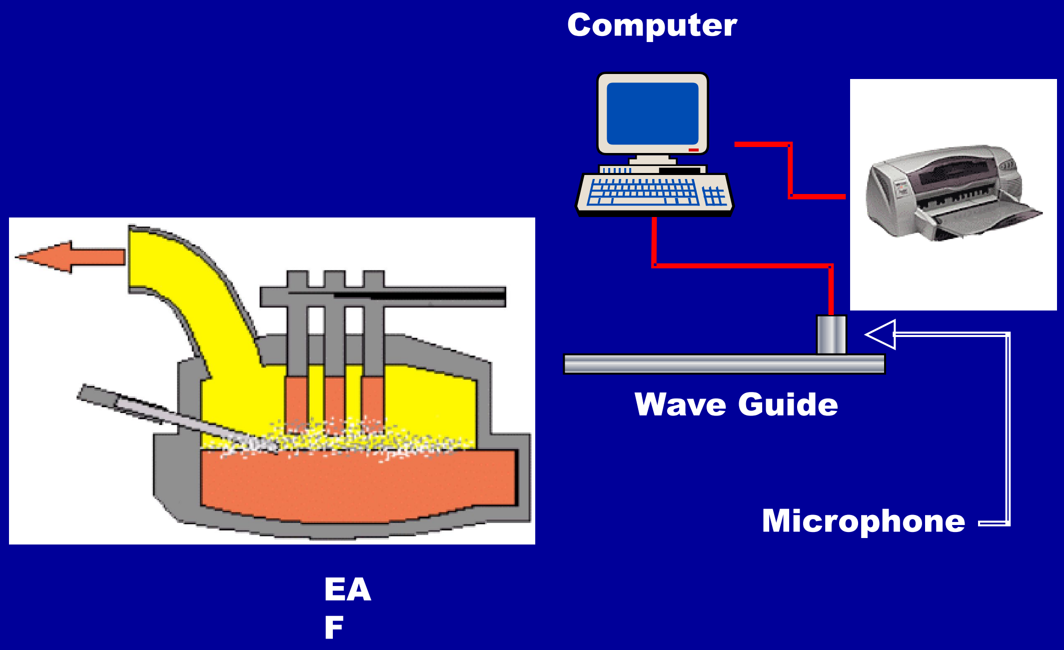
System Physical Principle

- The Accusteel System monitors the propagation of acoustic waves inside the furnace in order to gain the following critical process information:
  - behavior of the liquid phase of the steel and slag
  - real-time thermodynamic temperature of the entire bath (as opposed to the traditionally used instantaneous spot thermocouple temperature value)
  - chemical composition of the heat
  - carbon and dissolved oxygen content
  - required addition of deoxidation agents

System Configuration

- All relevant data of the ongoing melting process is displayed on the system monitor screen, allowing for real time visualization of changes of all key process parameters, as well as the subsequent analysis and optimization of the process.



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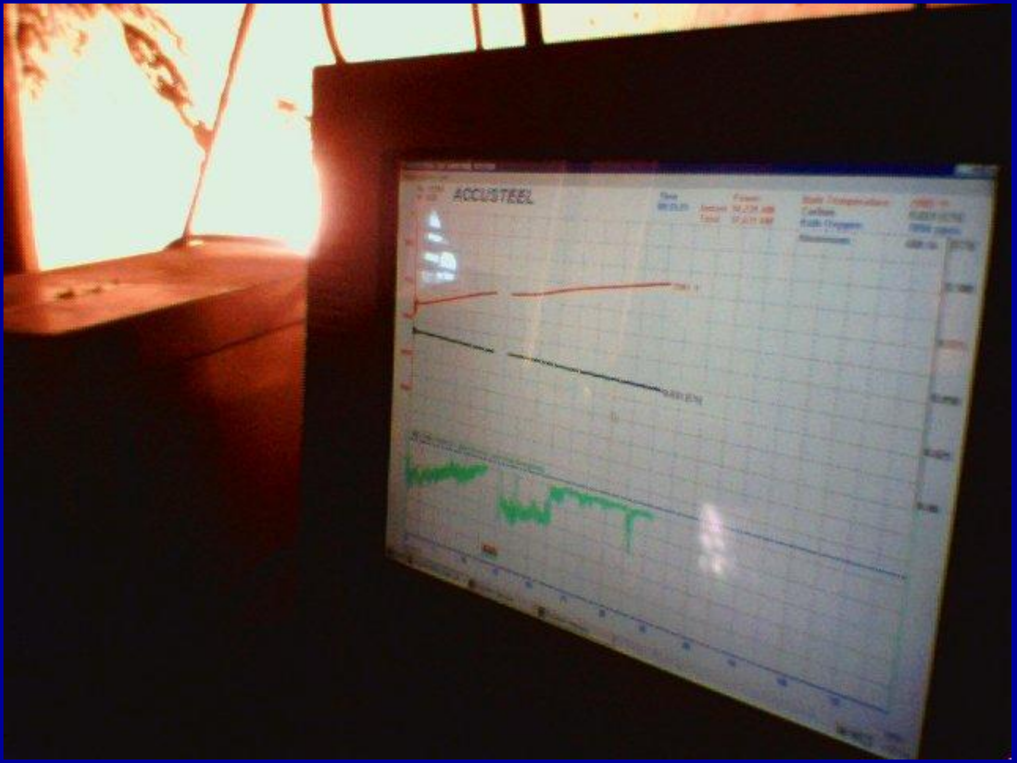
Operational Flexibility

- Unlike the monitoring systems based on the thermal and material balance calculations, Accusteel does not require accurate information on the charge chemistry and the composition of the waste gases.
- The system does not require the use and ongoing maintenance of numerous process monitoring instrumentation needed for continuous off-gas analysis.



- The inaccuracies of thermocouples themselves and inefficiency of spot temperature measurements are eliminated as well.

System Performance

- During six months of operation utilizing the process data received from the Accusteel System, a melt shop using a 150-ton direct current EAF was able to reduce the tap-to-tap time from an average of 55 minutes to less than 45 minutes with power-on time of about 34 minutes.
  - In this presentation “tap-to-tap time” includes the entire cycle time less the tapping time
- The analysis of trial heats clearly illustrates excellent correlation of the thermodynamic temperature and the carbon content of the heat when using the acoustic method, and lack of such correlation between test samples when using the thermocouple and indirect method of detecting the carbon content.
- Additionally, the acoustical system of measuring the process parameters is much more informative and accurate - due to the heterogeneity of the heat in the measuring area - than currently used systems.

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Economic and Process Benefits

- The expected economic and process benefits from using the information generated by the acoustical system are:
  - Reduced energy consumption - up to 10%
  - Reduced tap-to-tap time
  - Reduced consumption of de-oxidation agents, such as aluminum
  - Reduced electrode consumption
  - Eliminated thermocouple cost
  - Increased yield
  - Increased refractory life
  - Improved operator’s safety
- The magnitude of economic benefits realized from Accusteel Real Time Melter Control System would vary from plant to plant but the experience of our customers shows that the rewards are real and achievable.

Accusteel Trials

- During the 6-months trials a comparative analysis of two technologies for temperature, carbon and dissolved oxygen content measurement was conducted in a 150-ton direct current arc furnace:
  - thermocouple instantaneous local temperature measurement
  - versus acoustical real-time thermodynamic temperature monitoring.
- This analysis is based on the data received from the following heats:
  - 71 heats conducted in February-March
  - 146 heats conducted in April of 2003
- During these heats the following measurements were made:
  - 429 thermocouple temperature measurements
  - 488 acoustical thermodynamic temperature points
  - 418 measurements of carbon content made with the existing probes
  - 486 carbon content values depicted by the acoustical system
  - 410 measurements of the dissolved oxygen made with existing probes
  - 217 measurements of the dissolved oxygen made by the acoustical system

Trial Setup and Criteria

- Temperature values, carbon and dissolved oxygen content were analyzed from actual thermocouple samples and derived by the acoustical system.
- The thermocouple samples were taken in the specific area of the furnace and the results assumed to be representative of the entire bath.
- The temperature measured by the acoustic system is the integral thermodynamic temperature of the liquid phase in the furnace.
- The carbon content and dissolved oxygen are the function of the thermodynamic temperature.
- Calibration of the system was done using the average thermocouple measurements.

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Trial Results

- A correlative analysis was conducted to determine the accuracy and repeatability of both systems.

	Function	$T_t(T_A)$	$T_A(T_{Af})$	$T_t(T_L)$	$C(C_A)$	$C_A(C_{Af})$
Feb. – Mar. 2003	CORREL	-0.07631	0.957414	0.223741	0.066881	0.961121
April 2003	CORREL	0.093007	0.982067	0.321073	0.012475	0.977889

- The results of the analysis show the lack of correlation between the values measured by thermocouple and those determined by the acoustical system.
- The lack of correlation between measurements of the heat temperatures made by the thermocouple in the furnace (T_t) and those measured in the ladle (T_L) proves the lack of consistency of thermocouple measurements.
- On the contrary, values determined by the acoustical system indicate a high correlation coefficient and, therefore, are very reliable.
- The use of the data derived by the acoustical system allows for accurate control and optimization of the melting process with high level of reliability.

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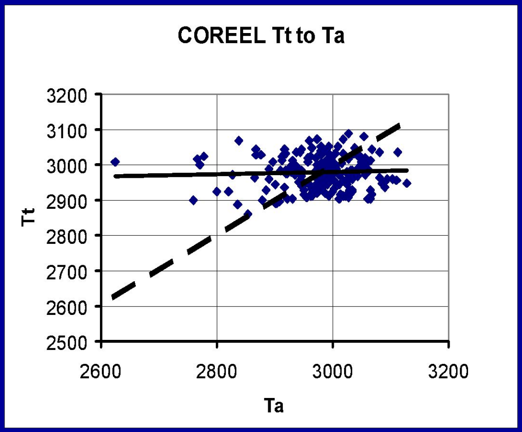
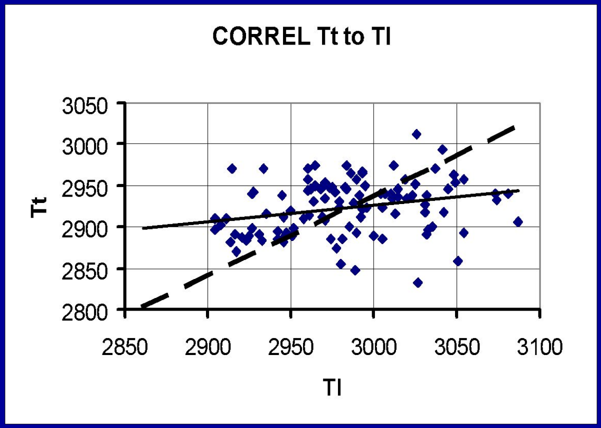
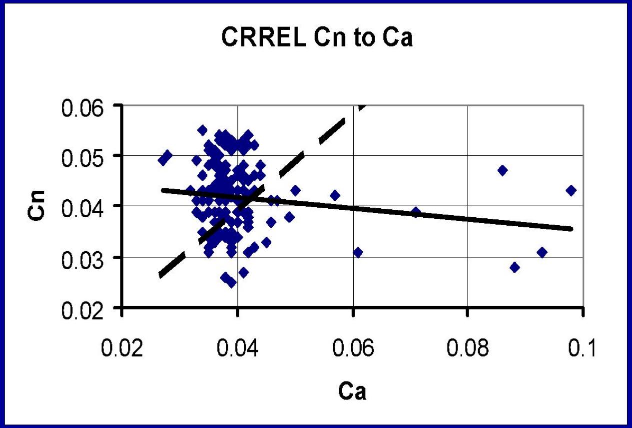
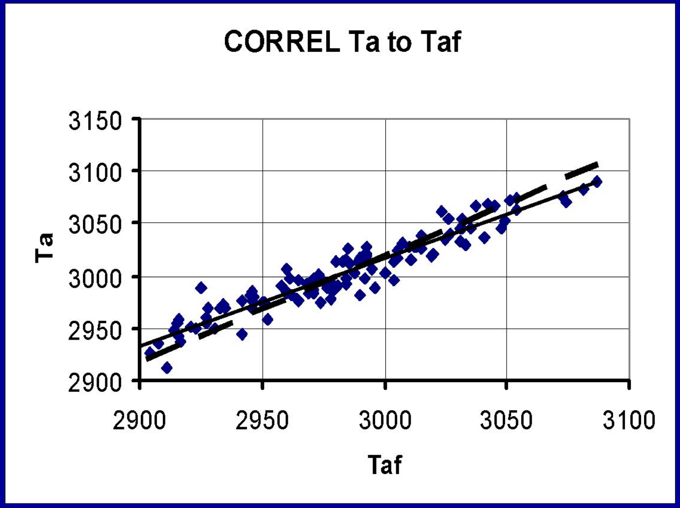
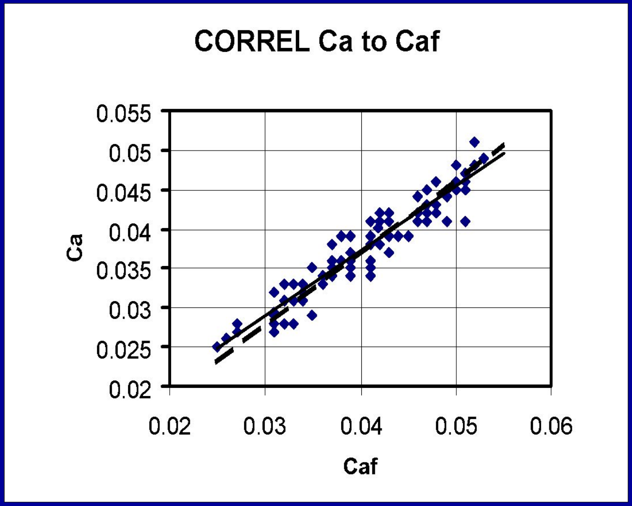
Correlation Analysis











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Trial Analysis

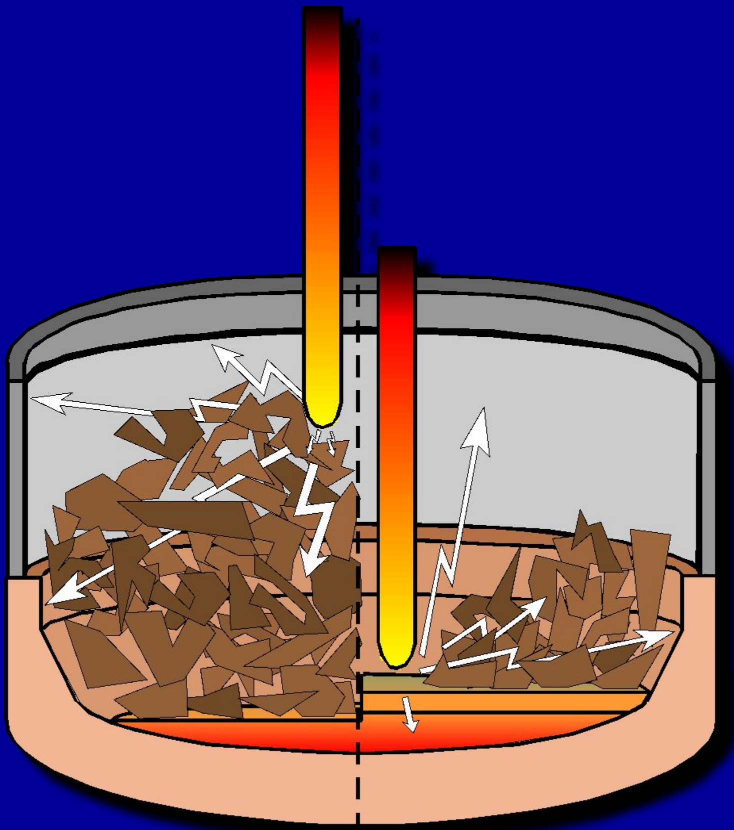
- Statistical and correlative analysis indicates that the average values measured by the existing thermocouple system and determined by the acoustical system are similar (or +/- 2^{o}F).
- However, the standard deviation of:
  - the thermocouple measurements is +/-55^{o}F
  - Accusteel measurements is about +/-30^{o}F.
- The standard deviation of the thermocouple measurements consists of:
  - +/- 20^{o}F calibration error of the thermocouple
  - the temperature gradient in the measured area.
- The standard deviation for the thermodynamic temperatures determined by the acoustic system is formed due to:
  - process deviations in the course of the heat.

Trial Analysis

- The lack of correlation between the values of temperature and carbon content measured with thermocouple and those determined by the acoustical system is caused by the differences in the physical principle of measurement systems being compared:
  - In the thermocouple - the measurement is local and, therefore, spontaneous.
  - In the acoustical system – the determined values are integral.
- The lack of correlation in the measurements of temperature, carbon and dissolved oxygen content made by the existing instrumentation proves the inconsistency of these measurements and, therefore, the lack of repeatability of the measurement methods.
- The results of the correlative analysis of the data received from the acoustic system have a correlation coefficient of between 0.96-0.98 - a clear proof of system accuracy, repeatability and reliability.
- Industry standards generally allow for any process with a 95% correlation coefficient to be considered accurate for use in practice.

Melting Practices

- Analyses of 217 heats utilizing the data acquired by the acoustical system indicate two distinctly different melting practices used by the arc furnace operators. These two practices can be observed in real time on the Accusteel display.
- The classification of the practices was made based to the initial temperature shown on the curve and according to the following criteria:
  - if the temperature within the first minute of the heat was lower than 2,900ºF, the heat was classified as Practice 1 – melting from the "bottom-up":
  - if the temperature within the first minute of the heat was higher than 2,900ºF, the heat was classified as Practice 2 - melting from the "top-down"



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Melting from the “bottom-up”

– Begins with intensive boring-in with long arc with rapid development of a vertical shaft in the scrap charge.

– Such intense melting results in fast rise of the liquid steel pool, which protects the furnace hearth and bottom electrodes when the arc reaches the bottom of the charge.

– During the first 5 minutes of the melting process liquid steel accumulates in the bottom of the furnace, forming a liquid bath and slag below the charge.

– From this point on, the melting continues with the long arc, positioned inside the vertical shaft, which is covered by the un-melted scrap, protecting the water-cooled panels and the refractory from excessive thermal radiation.

– Melting is done “from the bottom-up”, heat rises in the furnace preheating the un-melted scrap and, as scrap continues melting, the foamy slag level is rising covering the arc and protecting sidewalls.

– Next, the scrap covering sidewalls slides into the bath. By that time foamy slag level is high enough to completely enclose the arc and direct most of the arc energy into the bath, while protecting sidewalls from the radiant heat.

– The process is stable allowing for energy-efficient melting of the remaining scrap, since the upper layers of un-melted scrap are absorbing the heat generated by the arc, as it rises from the furnace bottom.

– Normally, at the time when the heat reaches the tapping temperature there is no remaining un-melted scrap in the bath or hanging on sidewalls.

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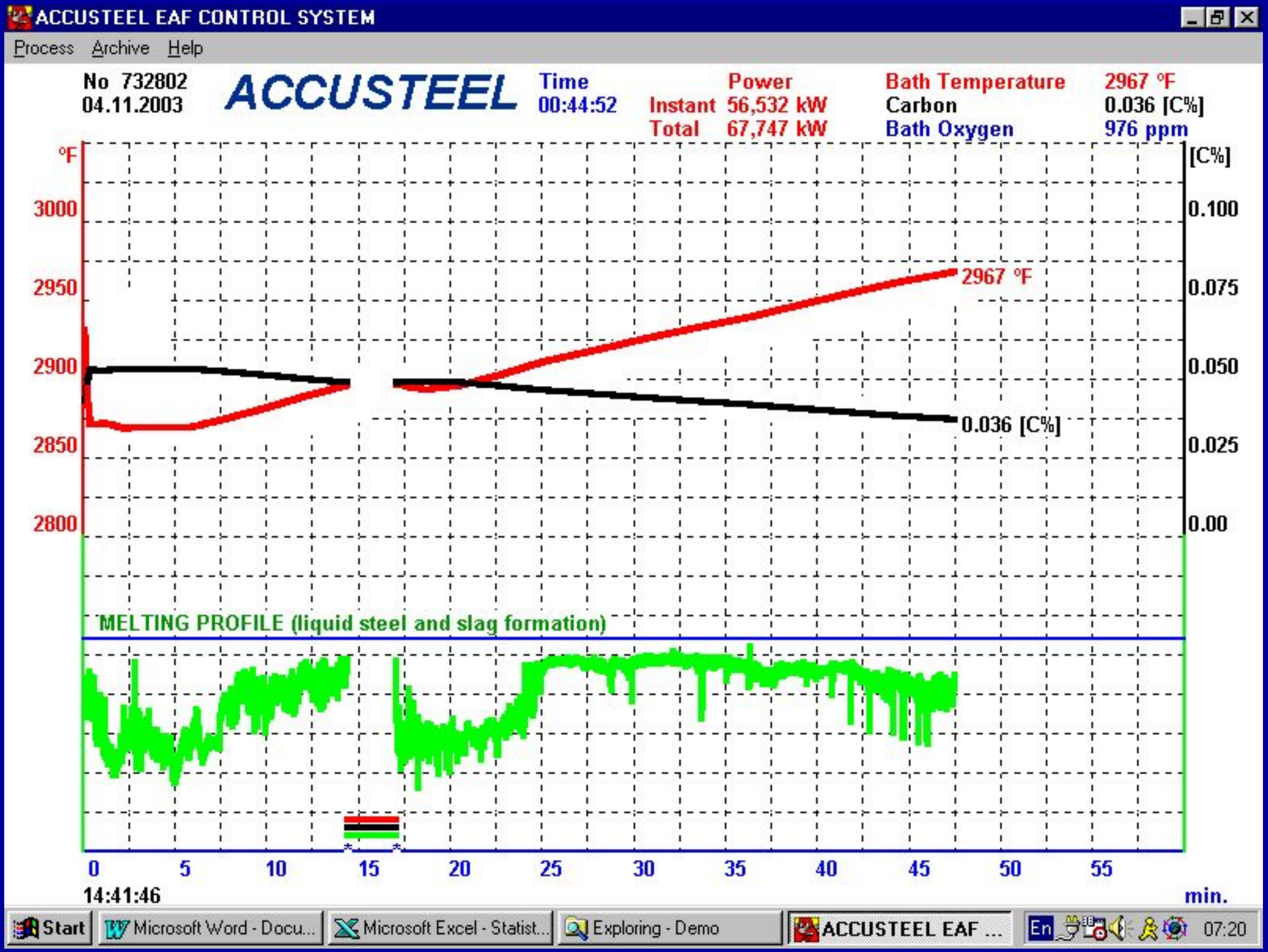
Melting from the "bottom-up"



Melting from the "top-down"

- Begins with slow boring-in with short arc without the formation of a vertical shaft.
- This leads to the formation of a small layer of liquid pool on top of the charge. The small pool of molten steel and slag remains on top of the un-melted scrap and due to its small volume ends up being continuously superheated at temperatures close to tapping.
- This liquid pool, not covered with foamy slag, can only partially absorb the arc energy.
- The melting process is done "from the top-down", useful heat rises into the open space, liquid metal is close to the water-cooled panels, and an open arc radiates heat towards the furnace sidewalls.
- This results in overheating of the water-cooled panels, substantial heat losses and decreased yield.
- As the volume of the liquid pool increases it continues gradually melting the upper layers of the charge directly beneath the liquid pool, leaving un-melted scrap on the bottom of the furnace even at the end of the heat.
- Such heats normally result in longer superheating time and increased energy consumption, overheated and overoxidized steel with heavy pieces of scrap or pig iron remaining on the bottom of the furnace
- Additionally, melting of pig iron close to tapping could result in high carbon content at the end of the heat.
- This Melting Practice could be caused by the high-density heavy scrap or pig iron, placed in the bottom or the center of the furnace charge, which would slow-down the boring-in process and require additional energy.

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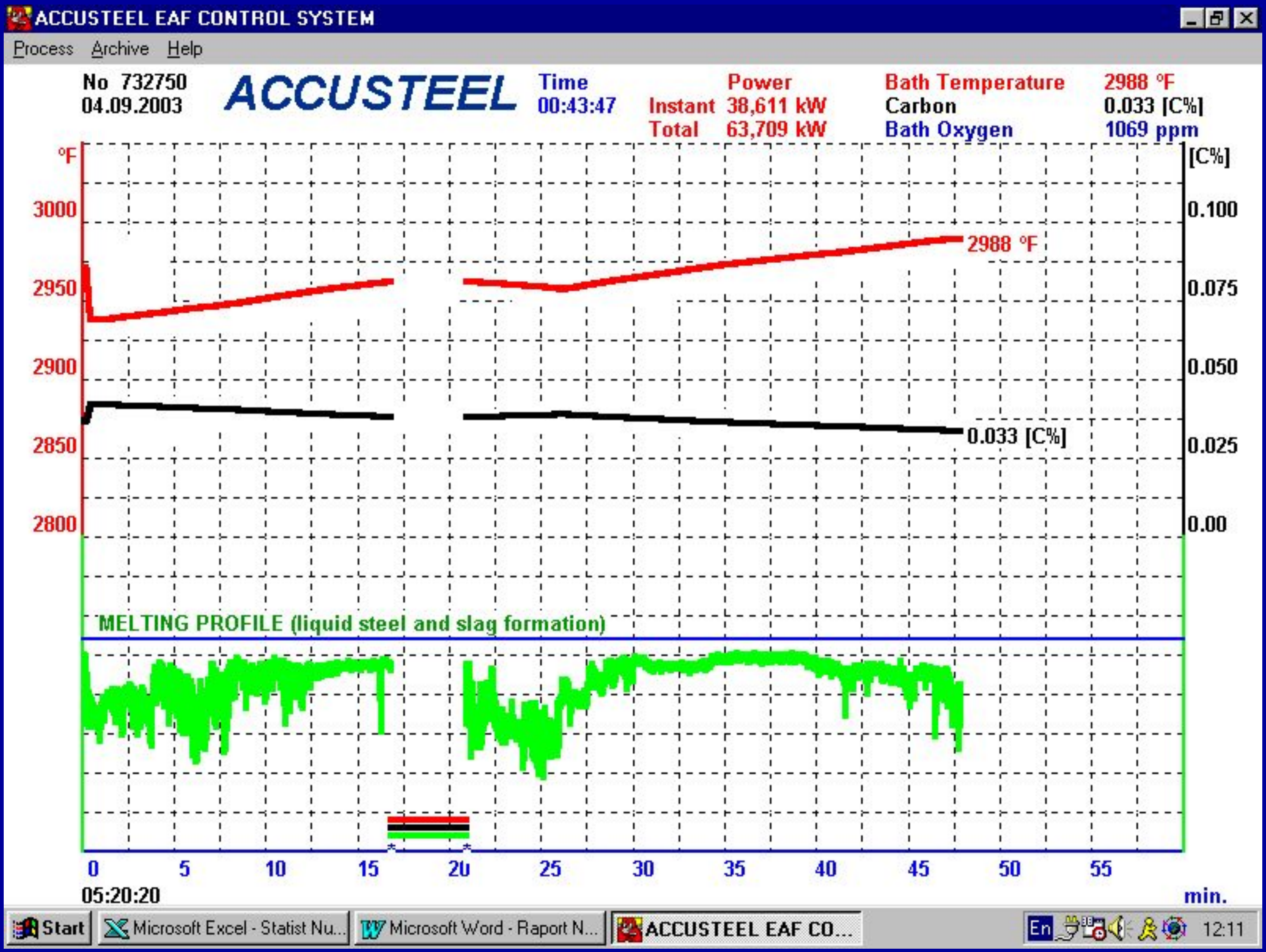
Melting from the "top-down"



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Economic Benefits

- Analysis of the trial heats indicate that 95% of the heats are conducted with an open or semi-open arc after partial deslagging in the end of the heat, which is necessary for the thermocouple temperature measurement.
- Superheating with an open arc on average takes about 10% of the cycle time.
- This results in excessive arc energy radiation, heat losses and potential damage to unprotected sidewalls.
- Temperature measurement with the Accusteel system does not require deslagging at the end of the heat.
- Therefore, using the Accusteel system will allow for up to a 10% energy savings, increased furnace productivity and equipment reliability.
- Considering the above factors the expected economic effect from using the Accusteel RTM system could be calculated as follows:

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Energy Savings

- The average energy consumption is 60 MW per heat.
- Saving 10% of electric energy results in 6 MW per heat.
- For a 150-ton heat this would result in savings of 0.04 MW of electric energy per ton of liquid steel.
  - 6 MW : 150 ton = 0.04 MW/ton
- <u>Electric Energy Savings Calculations:</u>
  - 150 ton/heat * 29 heats/day * 300 days/year (@ 7,200 operating hours/year) = 1,305,000 tons/year * 0.04 MW/ton = 52,200 MW/year * $30/MW = $1,566,000/year.

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Yield Increase

- Reduction in energy consumption also leads to increase in yield.
- Assuming that the total yield loss is about 10%, it is reasonable to note that, according to the industry accepted practices, approximately 6% of Fe is “burnt” into FeO (which ends up in slag) and 4% of iron oxidizes into Fe_2O_3 (furnace dust).
- If the total yield loss is 15 ton (10% of 150-ton heat), then 60% of this yield loss would amount to 9 ton.
- Therefore, lowering power consumption by of 10% would accordingly lower the yield loss by 10%, which is 0.9 tons per heat.
- <u>Yield Increase Calculations:</u>
  - 0.9 ton/heat * 29 heats/day * 300 days/year * $150/ton = $1,174,500/year
  - resulting in the production of an additional 7,830 tons per year

Productivity Increase

- Using the Accusteel system would allow for increase of furnace productivity by 8.7%.
- The average furnace cycle is 50 minutes and the average energy consumption is 60 MW per heat.
- The furnace power-on time is 40 minutes, which means that on average 1.5 MW are consumed per minute.
- Saving 10% of energy (6 MW) would decrease the furnace power-on time by 4 minutes.
- Decreasing the heat cycle from 50 minutes to 46 minutes would allow for 31.3 heats in 24 hours, instead of the 28.8 heats – 8.7% productivity increase.

Thermocouples

- On average, 2 thermocouples are used per heat at ~29 heats per day, which equates to 18,560 used annually.
- Thermocouple Savings Calculation:
  - 18,560 tc/year* $8.00/tc = $148,480/year.

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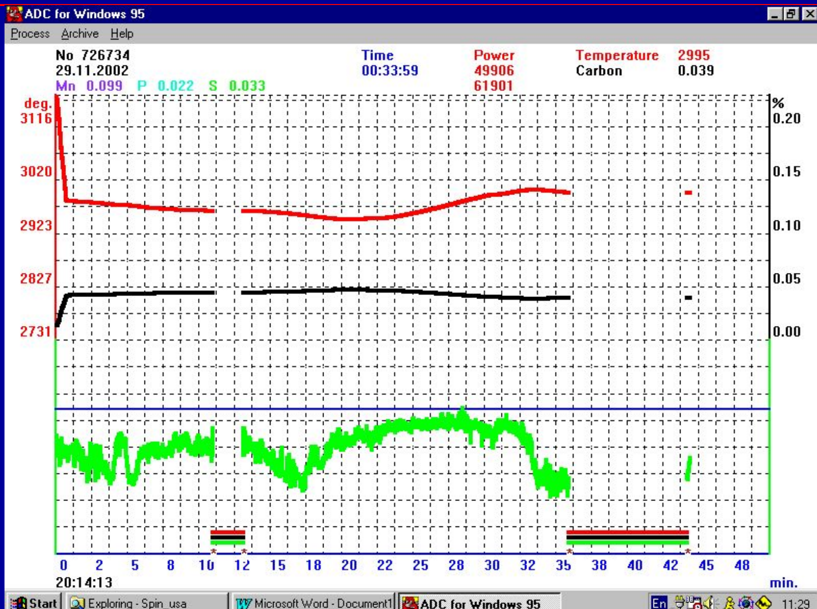
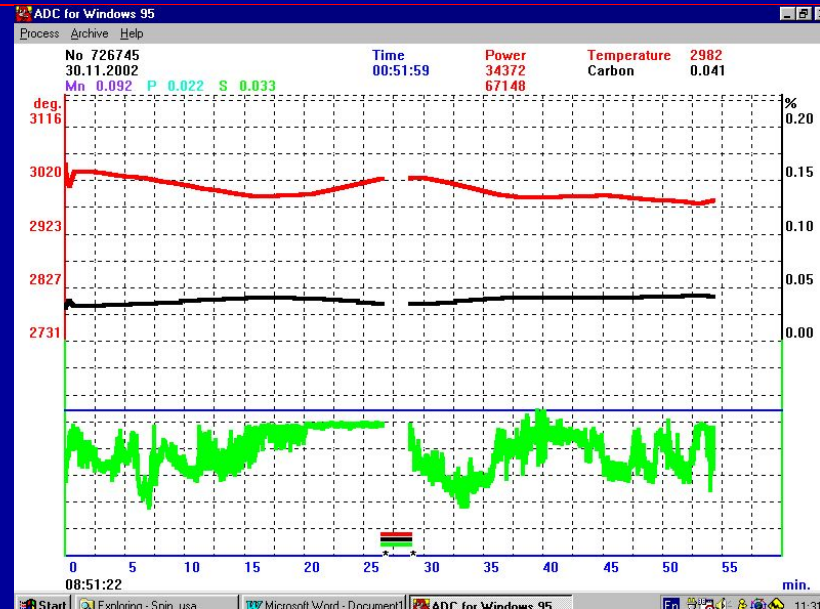
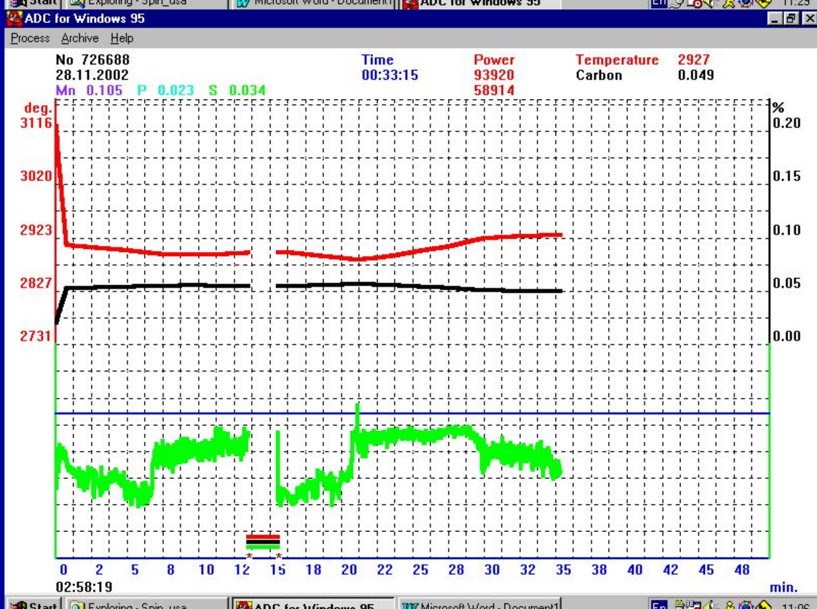
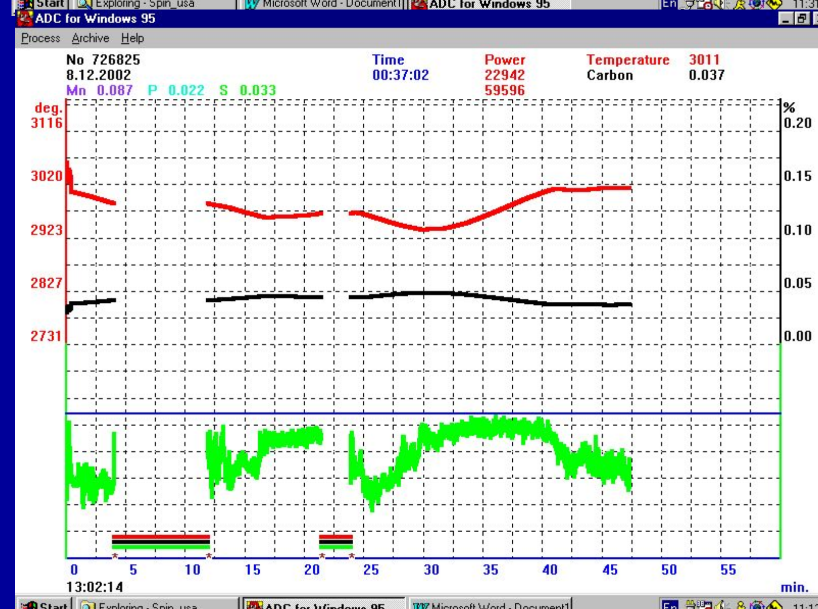
Initial Melting Practices









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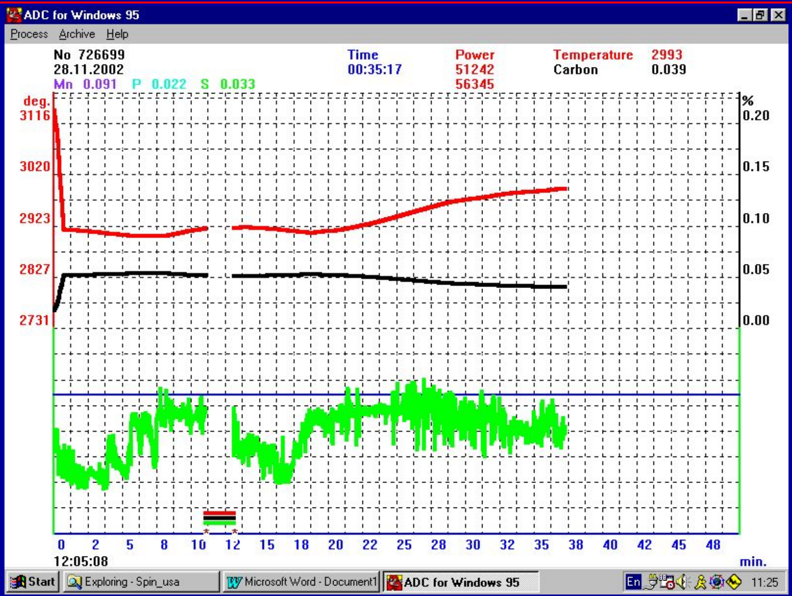
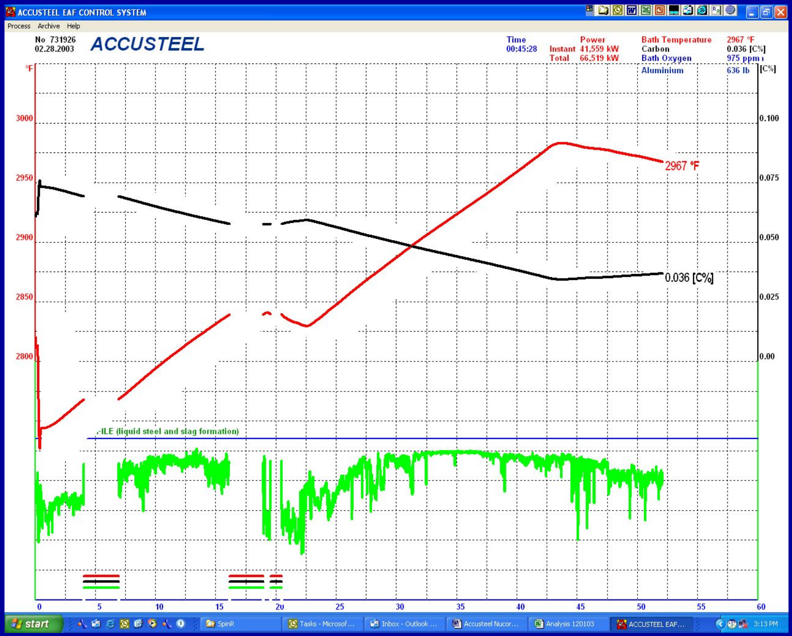
Initial Melting Practices





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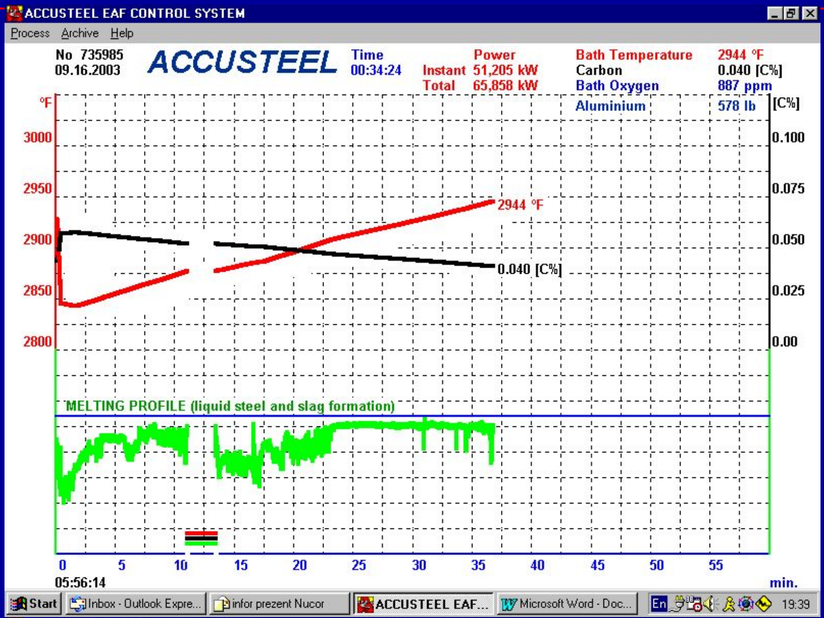
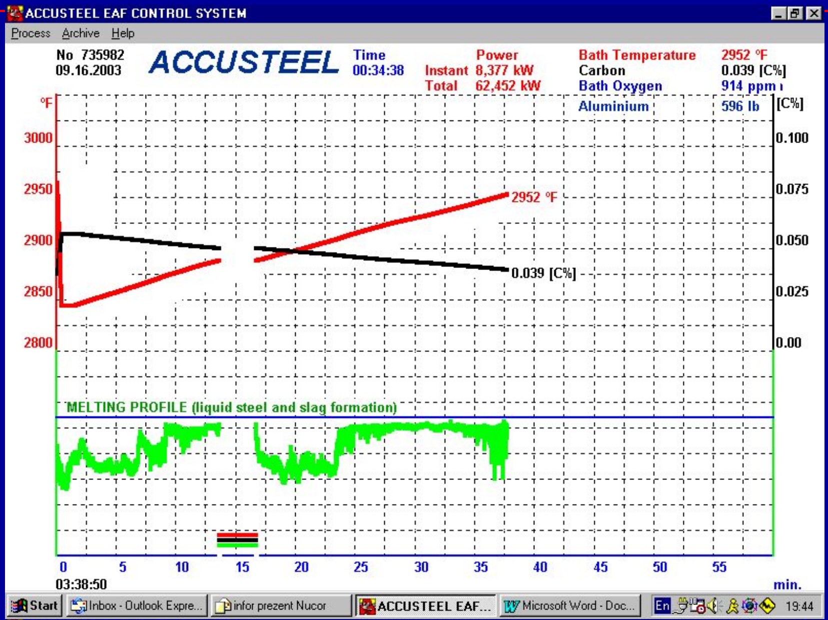
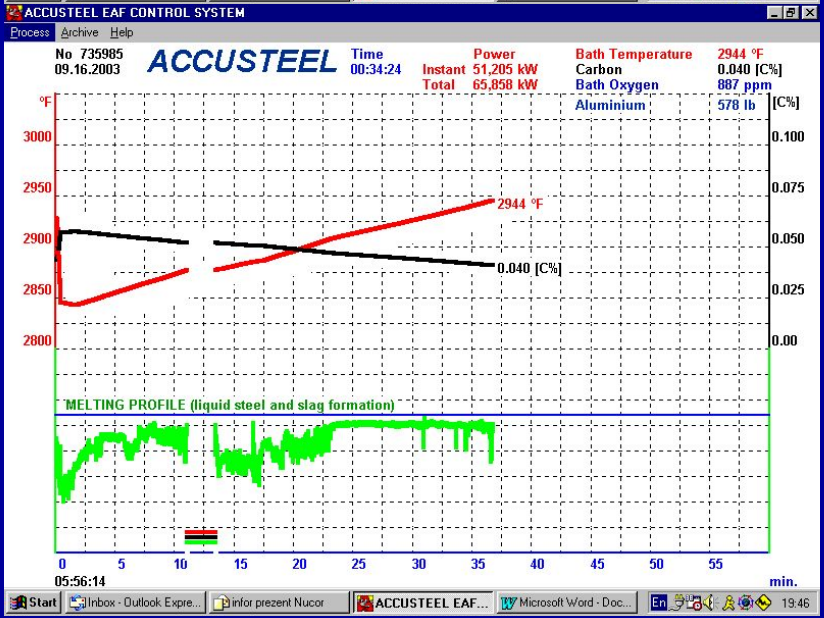
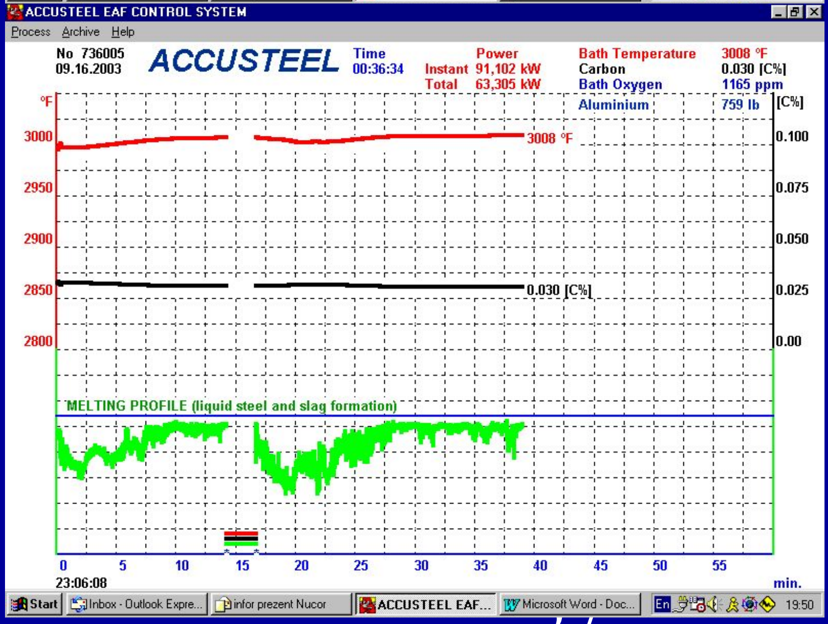
Improved Melting Practices









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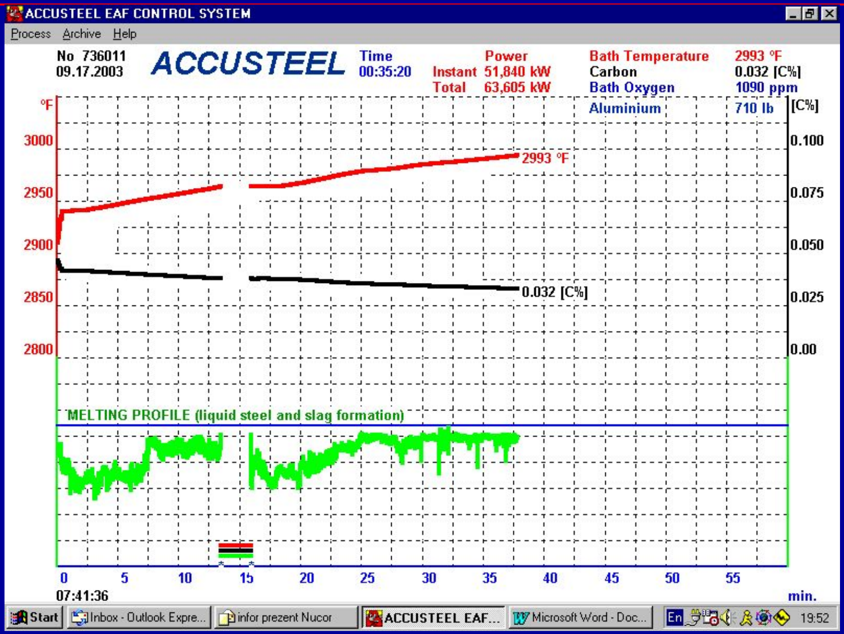
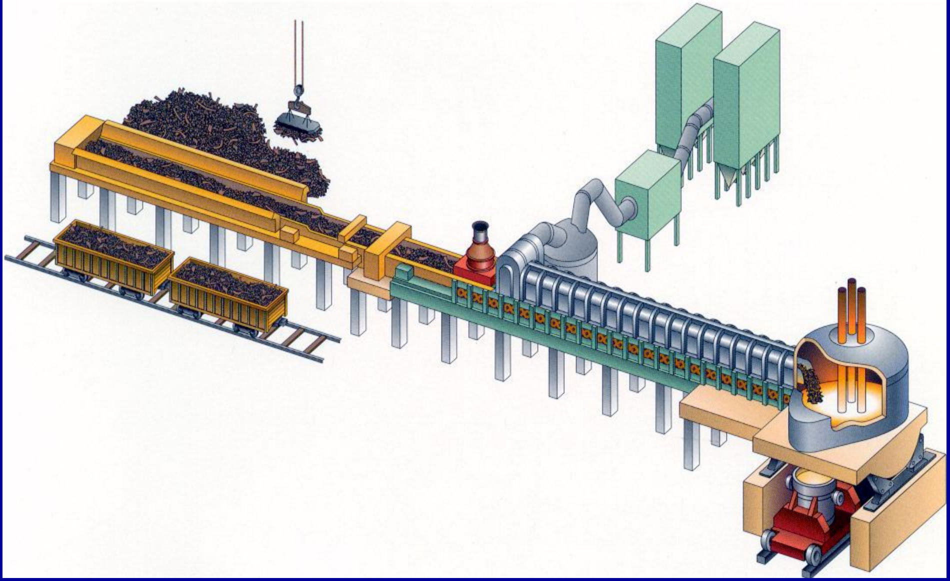
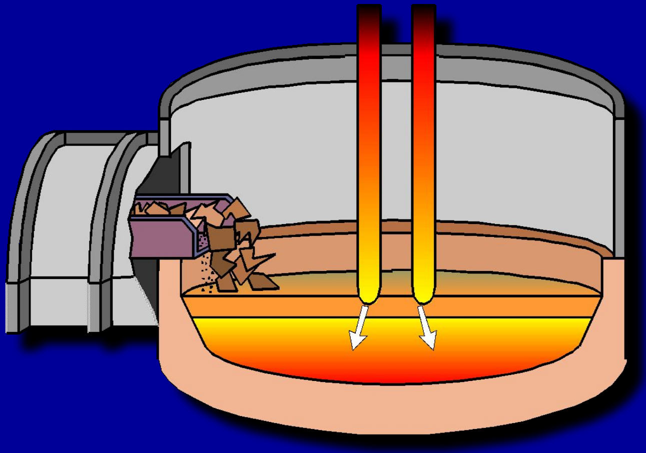
Improved Melting Practices



Consteel Application

- Potential Process Application :
  - Operate EAF at maximum power input
  - Continuously monitor the liquid steel temperature and carbon content
  - Regulate the Consteel charging rate by the steel temperature
  - Continuously monitor foamy slag behavior
  - Eliminated thermocouple use





Consteel Application

- The expected economic and process benefits :
  - Reduced energy consumption
  - Reduced tap-to-tap time
  - Reduced consumption of de-oxidation agents, such as aluminum
  - Reduced electrode consumption
  - Eliminated thermocouple cost
  - Increased yield
  - Increased refractory life
  - Improved operator’s safety

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Economic Benefits

- Based on Thermocouple savings only:
- On average, 7 thermocouples and 2 oxygen probes are used per heat at ~30 heats per day, which equates to 81,000 used annually.
- Thermocouple Savings Calculation:
  - 81,000 probes/year* $8.00/probe = $648,000/year.
- The values of other Economic Benefits are to be determined during the Accusteel System operation at a specific facility