Visualizing the Future in Steel Manufacturing

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ABSTRACT

Computer simulation and virtual reality visualization have evolved to become critical emerging technologies in creating immersive virtual environments for numerous fields. The ability to allow people to "go inside" these virtual environments provides a unique, and effective tool for understanding complex physical processes, and thus to innovate and to make significant improvements in a time and cost efficient way. It empowers people to work collaboratively and intuitively, and enables engineers to produce better designs as well as better solutions for troubleshooting and process/product optimizations more efficiently. As industry forges its way into the future, advanced computer simulation and visualization technologies will play an ever-increasing role in addressing the issues of productivity, energy, environment and quality, as well as workforce training to meet the challenges of tomorrow. The use of these technologies has already begun, and examples in steel manufacturing will be presented.

INTRODUCTION

Professor Keith Brimacombe was one of the first to apply modern scientific methods to improve understanding of complex metallurgical processes. He had passions for the training of young generations as well as for turning knowledge into reality. His dedication to education and steelmaking has inspired many people and has had profound impacts on the industry.   In his spirit of innovation and implementation, this paper presents a state-of-the-art virtual reality visualization technology and its application to steel manufacturing for process/product development to improve productivity, energy efficiency, environment, and quality.

WHAT IS VIRTUAL REALITY?

Virtual reality (VR) is a cutting edge technology that allows users to interact with computer-simulated environments based on computer graphics. The term VR was introduced in the late 1980es [Christiansson, 2001].   There exist many different definitions of Virtual Reality. According to Bryson [1996], VR is the use of computers and human-computer interfaces to create the effect of a 3-D world containing interactive objects with a strong sense of 3-D presence.

According to Svidt and Bjerg [2002], a VR system which creates a virtual environment, normally includes some of the following elements: "1) real-time interaction with the model including mouse or keyboard, tracking of persons, tracking of interaction devices, and haptic devices; 2) stereo viewing including active and passive; and 3) a certain degree of immersion including wide screens, power walls, large curved screens, Cave Automatic Virtual Environment (CAVE), or head mounted displays."

The introduction of the CAVE in the early 1990's allowed users of virtual reality a new level of collaboration, providing a shared immersive environment without the need to provide individual displays for each collaborator **Error! Reference source not found.**. A number of CAVE-like systems and variations have been developed by research groups as well as companies that have emerged specializing in the design and implementation of immersive systems [Spagno, 2003, Duncan et al., 2007, and DeFanti et al., 2009]. These systems offer a variety of options for size, resolution, brightness, tracking, and interaction.

Figure 1 shows a VR system at Purdue University Calumet's visualization facility called VisBox^{TM}. In this system, stereoscopic 3-D is provided with specialized projectors and Infitec glasses. It uses four projectors total, two for the front wall, and two for the floor screen. The lenses in the Infitec glasses correspond with filters in the projectors such that each eye only sees an image from the matching projector. User-centered display is achieved through the use of an InterSense tracking system. A series of strips on the ceiling emit rapid ultrasonic pulses that are interpreted by microphones on a head-tracker that is mounted on the user's glasses. This device lets the computer know where the user is and the direction that they are looking. Interaction is achieved through the InterSense wand, which has 6 buttons and an analog joystick-style thumb stick. The wand also provides position and orientation data that can allow the user to point at or even grab objects. A server-grade PC with high-end graphics cards is used for real-time VR visualization.

Figure 1 Hardware of the immersive VR system

WHAT IS THE SIGNIFICANCE OF VIRTUAL REALITY?

Virtual reality strives to immerse the user completely within an experimental simulation. This greatly enhances the overall impact and provides a much more intuitive connection between the computer and the human participants. VR can provide a remarkably collaborative, intuitive, safe, and productive immersive working environment which may be too dangerous or impossible to explore directly. VR enables a close inspection of a component or activity for any size of models. VR has been successfully applied to many diverse areas including art creation, urban planning, manufacturing, scientific visualization, engineering, healthcare, education, and training.

Computer simulators have been increasingly used for training in both military and civilian arenas. Good simulations can systematically provide a wide range of possible training scenarios with low cost and low risk. The desire for cost effective training methods has turned toward virtual environments, in which a trainee interacts with a 3-D computer-generated world by seeing, hearing, and even feeling simulated objects [Zeltzer, 1996].

VR is beginning to have a major impact on engineering by streamlining the process of transferring analysis results into design solutions. VR can be used to investigate complex 3-D data and to explore human interaction with products that are still in digital form. It creates a computer-generated world in which people in any specialty can easily understand. Even people who are familiar with interpreting analysis results can gain insights for understanding the root causes of observed problems and making changes in much less time. VR is becoming a fantastic technology for the design and optimization of industrial processes for
1) overview of all the data and close examination of specific data points
2) sharing insights about complex phenomena among non-experts
3) empowering people to work collaboratively and intuitively
4) reducing design time for better solutions;
5) enabling engineers to design, analyze, revise their designs and watch as those changes take effect in the virtual model
6) training students, engineers, and operators

According to Sangster, "When we evaluate a situation, it's difficult for us to gain a clear picture of exactly what's happening inside, because we're only able to look at raw data. But when Purdue Calumet installed its visualization lab, it allowed us physically to see everything. It makes it so everybody can see the exact same thing [Rose, 2009]." Hunter also commented that "The virtual reality lab helps field engineers take a step back to rethink, or at least confirm, what the field data is telling them. With this new technology, our engineers can take a look inside a pipe, for example, and examine it at a much closer level to identify corrosion or other emerging issues [Rose, 2009]."

The following are some examples to demonstrate the power of Virtual Reality visualization.

Virtual Reality Applications in Product Manufacturing

The fast expanding capabilities of VR technologies in the recent decade have provided possibilities for reducing the product development period and improving the quality of the production in manufacturing. VR can create an integrated, synthetic manufacturing environment exercised to enhance all levels of decision and control [Hitchcock et al., 1994, Tiruvannamalai, 2002]. People can control virtual machines inside a virtual factory and evaluate digital products in advance. Immersed in the virtual world, engineers can create and modify their products in real time, verifying immediately the effects of these modifications which can help for eliminating unexpected errors, resulting in the reduction of the overall process time and cost as well as save of countless hours and dollars wasted on product recall [Souza, et al. 2006]. Cobb [1995] predicted the following attributes of virtual environments applicable to manufacturing :

- modeling in "virtual clay" - dimensioning, reforming and orienting, coloring.
- rapid prototyping through interactive design and test facilities.
- walkthroughs around a factory floor.
- rapid switching of viewpoints, at exocentric, egocentric and object-centered locations
- training for operation or maintenance of equipment.
- visualization of several stages in a manufacturing process.
- ergonomics assessment of 'fit' between different user sizes and product dimensions.

VR applications in manufacturing have been classified into three groups; operations management, manufacturing processes, and design as shown in Table 1 [Mujber, 2004].

Table 1 Summary for virtual reality benefits in manufacturing applications [Mujber, 2004]

Virtual Manufacturing

Virtual Manufacturing (VM) is an evolving area of research that aims at integrating diverse manufacturing related technologies under a common umbrella, using VR technology. According to Altintas [2007], the goal of future manufacturing is to design, test and manufacture parts in a virtual environment before they are manufactured.

Applications of VM encompass the entire life cycle of a product. At John Deere Company' s production facility, VM is implemented for the installation of an arc welding production system [Owen 1994]. In this application, a virtual 3-D environment was created for design, evaluation, and testing of the robotic production system. The VM approach helped shorten the design-to-manufacturing cycle-time. ICun et al [1994] also reported VR applications such as the use of VM at The Boeing Company for the ergonomic evaluation of their airplane designs for operation as well as maintenance.

Virtual Prototyping

Recently, "virtual prototyping" technology has been used in the design processes of modern machine tools to reduce the cost and time of hardware testing and iterative improvements of the physical prototype. The virtual prototype of a machine tool is a computer simulation model of the physical product that can be presented, analyzed and tested like a real machine. It allows iterative changing of a virtual model during the design process. The advantages and the potential time savings by virtual prototypes are illustrated in Figure 2 [Altintas, et.al. 2005].

Figure 2 Comparison of the traditional design process and the design process with virtual prototypes [Altintas, et.al. 2005]

Figure 3 Integrated developments of modern machine tools with virtual prototypes [Altintas, et.al. 2005]
Advanced software packages have been developed for design engineers to evaluate and optimize critical product characteristics with virtual prototypes. A wide range of software tools is available for the different design-stages of a machine tool as shown in Figure 3. The virtual environment displayed in Figure 4 enables the engineer to import Finite-Element-Models of machine tools. The engineer can analyze the FEM data and get a realistic intuition of the design in the VR-CAVE [Altintas, et.al. 2005].

Figure 4 VR environment for the investigation of machine tools [Altintas, et.al. 2005]

VR Visualization of Process Simulations

Advanced computer simulation and visualization technologies provide an innovative way for industrial process design, optimization and trouble shooting. Virtual environments can be created for humans to understand extremely complex information through visualizing, manipulating, and interacting with computer-generated simulation and models. The following is an example of VR visualization of computational fluid dynamics (CFD) simulations

CFD simulation, that can provide detailed information on flow characteristics and answer many "what if" questions, has more and more widely been used for process design, optimization, and troubleshooting to improve productivity, energy efficiency, environment, and product quality in industry [Bakker et al. 1997, Chang and Zhou 1999]. CFD simulation, though complicated, can be very beneficial to the people who are involved in operating or designing a flow/reactor system. It can be used to train novice operators by providing detailed information regarding flow property distributions in a system. For experienced operators, CFD simulation is used to evaluate the system performance and to seek optimal operating conditions. It can also be used to develop strategies for control. Moreover, CFD simulation can be used by designers to develop new and improved processes by conducting computational experiments on innovative design concepts.

The CFD software numerically solves the governing equations of the flow properties on a computational grid with specified boundary and initial conditions. The governing equations are derived from the conservation laws of mass, momentum, and energy. These equations can be expressed in a common form:

(1)

in which ξ is a general flow property; x_i, i=1,3 are coordinates; u_i, i=1,3 are velocity components; ∂ is density, Γ is effective diffusivity, and S_ξ is the sum of source terms. Because of the complexity of a flow system, various CFD models need be developed in CFD simulations. Validations of CFD models are important for accurate simulations. Figure 5 shows a typical validation process for the development of CFD models.

Figure 5 A validation process for CFD model development

CFD simulations for industrial processes have become increasingly sophisticated since solutions are often three dimensional, multi-phase, as well as time dependent, resulting in considerable amounts of data. Interpolating and presenting the complex numerical data in a meaningful fashion is a key to effective communication between CFD experts and plant engineers. Traditionally, CFD experts develop mostly 2-D pictures and animations of their results to help make the information understandable. However, the 2-D pictures and limited 3-D views may be insufficient for plant engineers to extract the information significant to plant operation. Advanced visualization techniques are needed for CFD post-processing to improve the understandability and functionality of CFD simulations.

The power of VR visualization for CFD simulations was first demonstrated in 1992 by Bryson's numerical wind tunnel [Bryson and Levit, 1992]. Later, Primikiri and Harris (2002) integrated computational data into a virtual cave environment where the dynamic experience of CFD data can help enhance the understanding of thermal environments. The user can enter and move around freely to see environmental data at any particular point in urban space. Recently, VR technology has became an efficient means of visualizing and analyzing huge amounts of CFD data [Huang et al. 2004, McCorkle et al. 2004, Hardt et al. 2004, and Jain et al, 2006]. The integration of CFD with VR is a growing emerging research field which can provide virtual engineering (VE) systems. With a VE system, people will be able to assess the performance of a process using CFD simulation results from a first person perspective. The VE environment greatly enhances the value of CFD simulations for design and optimizations of industrial processes.

In the effort to integrate VR with CFD, significant progress has been reported by the research team at Iowa State University's Virtual Reality Applications Center. They developed the software package called VE-Suite, which allows users to examine fluid flow characteristics using immersive visualization and three-dimensional user interaction [McCorkle et al., 2004, 2007]. Recently, Purdue University Calumet (PUC) has established a new Center for Innovation through Visualization and Simulation (CIVS) and made effort to integrate open source software packages to visualize CFD simulations in virtual environments for industrial processes [Fu et al., 2009; Wu et al., 2010].

Figure 6 provides an overview of the process to create a virtual environment at PUC. To bring CFD data into the realm of VR requires a series of data conversions using several different software applications. After the conversion of the CFD results into the universal Visualization Tool Kit (VTK) format, the data is first converted into the Virtual Reality Modeling Language (VRML) format through the open-source software ParaView which is a multi-platform application designed to visualize data sets. The data is then interpreted and converted using an open source high performance 3D graphics toolkit OpenSceneGraph (OSG) library. A C++ class named VTK Reader is also used for data conversion. Finally, a series of virtual cameras are created using the VR Juggler software, which is an open source and a cross platform set of virtual reality libraries. VR Juggler acts as a bridge between the immersive system's hardware and the software. These virtual cameras are used to display images to the VisBox^{TM} projectors, which produces the stereoscopic 3D effect. The VR Juggler application allow users to develop various functions such as flying around inside the 3D data, stepping through a simulation over time (like playing an animation, forward or reverse), switching the method of visualizing a dataset (changing from streamlines to vector fields, etc.) and switching between different datasets. These functions can be linked to the different buttons on the wand, or added to a 3D menu. Customized functions including Virtual Probe and Flowing Vector have also been added to the VE application to provide interactive visualization. The Virtual Probe function allows interactive data retrieval quantitatively at any given location designated by a user. The Flowing Vector displays a trail of arrows that trace a path following the flow. This provides an alternative to visualizing the flow as static arrows.

Figure 6 A process to create a virtual environment

IMPLEMENTATION OF VIRTUAL REALITY VISUALIZATION TO STEEL INDUSTRY

The steel industry plays a major role in the North American economy. In the last two decades, significant changes in the steel industry have occurred including restructuring and rebuilding of the industry which brought about closure of many plants across North America [Peaslee, 1998]. In a technology-based global economy, the industry must continuously seek new initiatives to stay at the forefront of manufacturing technologies and to remain in a competitive position in the global marketplace.

Ironmaking and steelmaking involve capital and energy intensive processes. Efforts have been continuously made for process optimization

to improve productivity, energy efficiency, environment, and quality (PEEQ). To solve the steel industry's challenges especially in the PEEQ areas, advanced computer simulation and visualization technologies can play a critical role. Significant efforts have been made for industry implementation of mathematics models in steel processing [Thomas, 2009]. The integration of computational simulations and virtual reality visualization is now under development and can be applied to optimize existing processes, develop new processes and products, as well as train students, engineers and operators. The following are some examples of such applications.

Virtual Steelworks

The World Steel Association has initiated the Steel University [www.steeluniversity.org]. According to the website "It aims to provide a comprehensive package of highly interactive, informative, innovative, integrated and sophisticated e-learning resources on steel technologies, covering all aspects of iron and steelmaking processes through to steel products, their applications and recycling". The web-based modules have been developed for education and training. One of the modules is the Virtual Steelworks as shown in Figure 7. In this 4-D "fly-through" module, people can learn a first-hand overview of the main production processes in a modern steelmaking facility, which starts at a ship unloading iron ore and ends with the finished steel.

Figure 7 Virtual Steelworks [www.steeluniversity.org]

Blast Furnace

The driving forces for technological improvements are particularly strong in the ironmaking process, since the extraction of iron from ore is capital and energy intensive. A blast furnace represents the predominant iron-producing process in North American. Due to difficulty in measurements, advanced CFD simulation has been recognized as a powerful technology for improving blast furnaces. Recent rapid advancements in computer technology have made the development of high fidelity CFD simulations possible. Such simulations are a powerful tool that can be used to (1) gain fundamental insights, (2) investigate the impact of key operation and design parameters, and (3) develop strategies for process optimization.

Since 2003, a North American research consortium has been formed at PUC to develop state-of-the-art CFD software packages for blast furnace simulations. Specifically, copyrighted CFD codes have been developed for blast furnaces hearth, pulverized coal injections (PCI), and gas distributions. Commercial CFD software has also been used to simulate some components of a blast furnace. Recently, virtual reality technologies have been added to enhance the understanding of CFD simulation results and to develop a virtual blast furnace for training as described in the following.

Virtual Blast Furnace

A virtual blast furnace (VBF) is being developed under the FeMET Design Grant supported by AIST and AISI [Fu et al. 2009]. The VBF displays all the major components and phenomena in a 3-D immersive virtual environment. It can be used in training workshops. As shown in Figure 8, by walking into a blast furnace during "operation" which is impossible in reality, people can learn how a blast furnace works in a more effective way comparing to the traditional Power Point presentations. It also provides a more intuitive way to understand CFD simulation results both qualitatively and quantitatively. Furthermore, it can be used to stimulate students' interest in the steel industry, which may result in a generation of engineers and operators in the industry. Click here for a 3-D Video of a Blast Furnace.

(a) Outside view (b) Bottom view (c) Inside view
Figure 8 A virtual blast furnace for training

CFD Simulation and Visualization of a Blast Furnace Hearth

A blast furnace hearth plays a critical role in the campaign life of a blast furnace which is limited by the wear of the hearth refractory [Huang et al. 2005]. A longer campaign life can significantly lower costs and increase productivity because less blast furnace downtime and financial cost would be needed for repairs and refractory relining. In order to help monitor and control the hearth erosion process, CFD models and methodologies have been developed specifically for the hearth simulations and incorporated into a CFD code [Yan et al., 2005; Chaubal and Zhou, 2006; Roldan et al. 2007, Zhang et al., 2007 and 2008; Huang et al. 2006 and 2010]. Specifically,

- It is truly 3-dimensional and can simulate non-uniform refractory thermal conductivity distributions and thermal connections, as well as actual asymmetric inner profiles.
- It includes a complete real geometry including deadman, hot metal flow domain, blowing layer, skulls, refractories, ram, and steel shell.
- It can simulate both steady and unsteady state flows.
- It can include species calculations as well as multiphase (hot metal and slag)
- It can predict flow characteristics, temperatures of hot metal and refractories, inner profiles, and liquid level
- It has been extensively validated using both laboratory and plant measurements.
- It uses a graphical user interface preprocessor for easy creations of geometry and grids.
- It can integrate with VR to create a virtual blast furnace hearth

CFD simulations have been conducted extensively for various applications. The results have provided visualization of flow patterns and inner profiles, helped design monitoring systems for refractory temperatures, helped develop recommendations for CFD-based strategies for extending campaign life, as well as provided trouble shooting solutions. With the integration of CFD and VR, the user can "enter" the full scale hearth and inspect the 3-D erosion profile and skull build up as shown in Figure 9.

(a) Outside view   (b) Inside view   (c) Flow characteristics and erosion pattern

Figure 9 CFD simulation and VR visualization of flow characteristics and internal profile in a blast furnace hearth

CFD Simulation and Visualization of a PCI Process

Pulverized coal injection (PCI) has been recognized as an effective way to decrease in coke and total energy consumption for primary metal production along with minimization of environmental impacts [Ishii, 2000]. However, increasing the amount of coal injection into a blast furnace is currently limited by the lack of knowledge of some issues related to the process. It is therefore important to understand the complex physical and chemical phenomena in the PCI process. Comprehensive 3-D multiphase reacting CFD models have been developed to simulate the PCI process with real furnace conditions. These models provide raceway size and distributions of flow properties such as velocity, temperature, pressure, species, particle number density, reaction rates, and unburned char concentration. Validations have been made by comparing CFD results with experimental data. A number of simulations have been performed for different blast furnaces. The results have provided guidance for understanding and optimizing the PCI process. Recommendations have been made for the strategies of increasing PCI rate, the guidance for design and protection of PCI lance, and the solutions for trouble shooting [Zhao et al., 2005, Gu et al., 2006, 2007; Selvarasu, et al., 2007, Walker et al., 2007, 2008; Tian et al., 2008, Huang et al. 2009]. Figure 10 demonstrates the CFD simulation and visualization of a PCI process.

(a) Flow vectors inside a tuyere   (b) Raceway formation   (c) Temperatures in a raceway

Figure 10 CFD simulation and VR visualization of a PCI process

CFD Simulation and Visualization of Burden and Gas Distributions

Gas and burden distributions are directly coupled to the fuel efficiency and pollutant emissions of a blast furnace [Tanzil, 1990]. An improvement of the blast furnace fuel efficiency contributes to the reduction of energy consumption in the steel industry because this process represents about 70% of the total energy input to the industry. The gas distribution, i.e., the effective contact between the gaseous reductant and the iron ores, strongly influences both thermal and chemical phenomena in the lumpy zone of the furnace. The gas distribution, which also affects the pressure loss as well as productivity and smoothness of operation, is controlled mainly by manipulating the distribution of the burden and tuyere operation. The proper gas distribution is also a key to realizing high rate PCI rate and high fuel efficiency. The knowledge of gas distributions and its influential factors in a blast furnace is essential for process optimization.

A 3-D CFD shaft code has been developed for the upper part of the furnace which includes burden distribution, gas distribution, gas-solid reductions, gas-solid heat exchange, cohesive zone, furnace permeability and chemical reactions. The coupling of the shaft code and PCI code can provide detailed gas distribution at different operating and geometric conditions [Fu et al., 2009]. It is now being used to (1) investigate the impact of key operation and design parameters and (2) develop strategies to maximize gas utilization and fuel efficiency and to minimize pollutant emissions. Figure 11 demonstrates the CFD simulation and visualization of a PCI process.

(a) Overview   (b) Cohesive zone   (b) Inside view

Figure 11 CFD simulation and VR visualization of gas distributions

Iron Ore Agitator

A chemical leaching process using mechanical agitation in a vertical tank is employed to remove solid impurities from iron ore in a liquid phase that can be separated from the solids [Kokal, et al. 2003]. In this system dilute sulfuric acid is used to dissolve phosphorus into the liquid phase, requiring proper mixing and suspension of solid iron ore particles in the liquid phase for optimum performance of the leaching process. During this process, it is important to achieve a high degree of extraction yet avoid the accumulation of coarse and dense ore particles in any of the tanks. The performance of an individual agitation system is highly dependent on many factors; such as impeller blade design, impeller blade location and shape, interior tank, impeller rotational speed, ore particle diameter and specific gravities of the solid and liquid phases. There was an issue at a plant that the non-uniform particle suspension affected the discharge composition and flow. To solve this problem, a thorough understanding of the flow characteristics and mixing is desired. This has been achieved through a multiphase transient CFD model. A number of simulations have been performed to investigate the impacts of geometrical and operation conditions on mixing. It was found that the original design has little vertical movement. An optimized design has been recommended for uniform particle suspensions [Wu et al. 2008, 2009].

Figures 12 (a) and (b) show the original design with a turbine-type blade and the optimized design with propeller-type blade and an additional six baffles respectively. A more even distribution of solid ore particle was observed throughout the tank for the improved design as indicated by more uniform color of ore volume fraction in the tank. The virtual environment as shown in Figure 12 (c) allows people to observe and inspect the transient data inside the tank during the entire process. Click here for a 3-D Video of an Iron Ore Agitator.

(a) Original design   (b) New design   (c) Inside the new agitator

Figure 12 Transient agitator data in immersive system

Preheating Furnace

As an important part of the coating lines, preheating furnaces are used to provide a uniform heating environment for the strip before it is coated by aluminum. A good understanding of flow characteristics and heat transfer inside a furnace will allow for increased production efficiency and product quality.   A transient 3-D turbulent reacting CFD model that includes natural gas combustion and moving mesh technique has been developed to simulate a preheating furnace. It has provided detailed velocity, temperature, and species distributions inside burners and furnace, as well as temperature distributions inside the steel strip at any given time. Validation of the model has been conducted with good agreement between the measured data and simulation results. The parallel computation on a multiple node cluster was employed to enhance computing capacity. A Virtual Reality System has been employed to assist visualization and analysis of detailed simulation results [Wu, et al. 2009].

As demonstrated in **Error! Reference source not found.**, the detailed information inside the furnace and burners can be closely inspected based on CFD simulations and virtual reality technology. The quantitative information of species concentration, temperature, pressure and other CFD calculated results can be retrieved at any location of the furnace. Detailed flow characteristics inside a burner can also be viewed by "walking" inside a flame. The integration of CFD simulation and virtual reality visualization has enabled direct observation on the detailed flow characteristics in a preheating furnace, resulting in insights into optimization of the furnace performance. Click here for a 3-D Video of a Preheating Furnace.

(a) Preheating furnace with a moving steel strip   (b) Flow characteristics below the steel strip

(c) Stand on the surface of the strip   (d) From inside of the flame

Figure 13 CFD simulation and VR visualization of a preheating furnace

Reheating Furnace

Reheating furnaces play an important role in the production of flat steel products. Steel billets are loaded into these furnaces for heating before running through a hot strip mill. The final roll quality is highly dependent on the uniformity of the temperature distribution inside of the furnace. These furnaces can have significant impact on product quality and total cost [Trinks, 2004]. To gain insights for optimizing the reheating furnace performance with high quality and energy efficiency, CFD has been used to simulate the whole operating process to exam the transient three dimensional velocity and temperature fields inside a furnace and to monitor the heating progress for each billet [Wu et al, 2007, 2008]. Validations have been conducted to compare CFD results and the measured temperature data. Parametric studies have been performed to investigate the effects of door opening, billet spacing, risers, burners, and furnace configuration. The immersive virtual environment as shown in Figures 14 enables people to observe the detailed flow patterns inside a furnace. People can also "walk" around inside the full scale furnace to observe the flow velocity, temperature, pressure, etc. at any location desired. Figure 14(a) is a top view of a furnace after charging all the billets. Figure 14 (b) shows flow vectors and temperature distributions near flames and a door which indicates some amount of hot gases are escaped from the door, resulting energy loss. Recommendations have been made for increased energy efficiency and product quality. The virtual furnace provides a very intuitive understanding for the furnace operation as well as CFD simulation results. Click here for a 3-D Video of a Reheating Furnace.

(a) Overall view of the reheating furnace   (b) Close view near a door

Figure 14 CFD simulation and VR visualization of a reheating furnace

Venturi Scrubber

The venturi scrubber is an air pollution control device to remove particulates emitted from a sinter plant. In this system liquid water is injected from multiple nozzles to entrap particulates into the liquid phase. The mixture of dust particles and liquid water is then separated from the exhaust gas at the cyclone separator connected to the venturi scrubber, and discharged from the drain hole. The clean air is discharged into the atmosphere. A good performance of this system requires efficient water circulation inside the throat as well as general reliability, which is highly dependent on many factors such as water jet design, nozzle location and shape, water flow rate, etc.

One of challenges in an existing plant is excessive wear on the side wall of the throat, which leads to considerable production downtime. The frequent downtime, therefore, diminishes the reliability and efficiency of this pollution control equipment. Achieving a reduction in wear and effective optimization of the scrubber's efficiency requires a better understanding of the flow inside the device. A 3-D multiphase CFD model has been developed to simulate three-phase flows in the throat of a venturi scrubber [Wu et al., 2010]. An optimized design has been recommended after analyzing and evaluating the CFD simulation results at different designs in a virtual environment. Figure 15 displays water flow streamlines and shear stress distributions with red indicating the highest value and blue indicating the lowest value. In general, a high shear stress caused by water impingements correlates to wear of the wall. The CFD results have shown proper nozzle angles can avoid water impingements which not only reduce the wear of the wall, but also increase the water utilization and particulate remove efficiency. With the aid of VR visualization, the solution was found in a very short time. Click here for a 3-D Video of a Venturi Scrubber.

(a) Top view   (b) Inside view

Figure 15 CFD simulation and VR visualization of a venture scrubber

FUTURE DEVELOPMENT OF VR TECHNOLOGY

Although VR visualization and simulation technologies have made great strides in recent years, these fields are still relatively young and there are many opportunities for continued development. Recent advances in graphics cards allow for the building GPU clusters that are capable of processing and generating simulation data many times faster than traditional methods [Kindratenko, 2009]. Using high performance computing resources such as these and coupling them with VR visualization has the potential for near real-time data visualization. In addition, 3-D display technology continues to advance and auto-stereoscopic systems are becoming available that allow viewers to see 3-D without the need for glasses [Tao, 2009; Stolle, 2008]. Remote visualization is also being explored to provide viewers a method of benefiting from VR visualization without the need to travel to a specialized VR facility. Another potential avenue for remote visualization is a technology called Augmented Reality (AR). With AR, computer generated imagery is displayed on top of a live view of the real world [Schall et al., 2008]. By combining AR with simulated data, viewers will be able to use mobile devices such as cell phones to see modified designs and simulation results as they would appear on site in the real world. In addition to implementing the forthcoming technological advances, the development of more integrated software with smoother flow and enhanced interface is ongoing.

Conclusion

The steel industry is facing many challenges in the global economy. Its future relies on the infusion of advanced technologies. Advanced computer simulations and visualization technologies can help the industry to maintain competitiveness and stay in the forefront of emerging technologies. The integration of computer simulations with virtual reality has been used with great success to convey highly complex calculations and data to a wide variety of audiences. Compared with an ordinary desktop computer, the immersive system gives a much more persuasive experience to achieve better interdisciplinary communication. It provides a collaborative and

intuitive way to visualize complex simulation results and has been proven to be powerful, cost-effective, and fast to get better solutions for industrial process design and optimization.

The continuous quest for high quality products, lower manufacturing cost, and faster time to market will force many manufacturing enterprises to change their manufacturing strategies, processes, and practices for product development. VR Visualization technology represents an important step toward the factory of the future by providing the ability to make changes in a virtual environment, saving money and time, and resulting in better designs of products.

The future of virtual steel manufacturing is exciting. The application of VR visualization in steel manufacturing offers many challenges but also enormous potential, both for research and implementation.

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