Analysis of Chemical Processing Equipment

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Abstract:
A typical chemical processing unit processes a large amount of fluid [1]. Given the economics of most unit operations, even small improvements in efficiency and performance can result in significant increase in revenue and savings in costs. Methods to predict the performance of a unit under a wide variety of operating conditions are required so that improvements in efficiency and hence in costs can be realized. The flow field in a chemical processing equipment is very complex and conventional methods of analysis are not adequate. Computational methods provide a viable tool for analysis and trouble shooting of such equipment.

Introduction:
A typical chemical process plant involves fluid flow devices such as pipes and valves. Fluid transport equipment such as pumps, compressors are employed for moving fluid from one unit operation to another. Drying equipment such as fluidized beds, cyclone driers, spray driers form an essential part of many processes. Dynamic and static mixing equipment are at the heart of most chemical processing plants. Heat generation and heat transfer units such as boilers, furnaces, burners, process heaters, heat exchangers, evaporators, condensers are employed for generating and transferring heat essential for various processes. Separation equipment such as cyclones, electro-static precipitators, hydro-cyclones, centrifuge separators, gravity separators are employed for gas-solid separation, gas-liquid separation and liquid-solid separation. The flow fields in these units are very complex and difficult to measure. Trouble-shooting as well as improvements in efficiency require multiple data points, which very often are unavailable. Failure of a chemical process equipment can result in undesirable down-time and loss of revenue. Reliable methods of analysis and trouble shooting of equipment are required.

Computational fluid dynamics (CFD) methods can be applied to examine different equipment designs, or compare performance under different operating conditions. Studies to examine the influence of various parameters on flow behavior and hence

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performance can be conducted using CFD methods. It also allows for various concepts to be examined in a virtual setting, without actually building a physical model. Equipment at its full-scale can be analyzed, thus scale-up related issues can be eliminated. These methods provide an inside look into the function and operation of process equipment and provide valuable information to equipment manufacturers, plant managers, production managers, process engineers and research and development staff.

At a chemical process plant CFD can be applied for diagnosis, analysis and trouble-shooting; it can be applied for prototyping and performance evaluation of process equipment as shown in Figure 1.

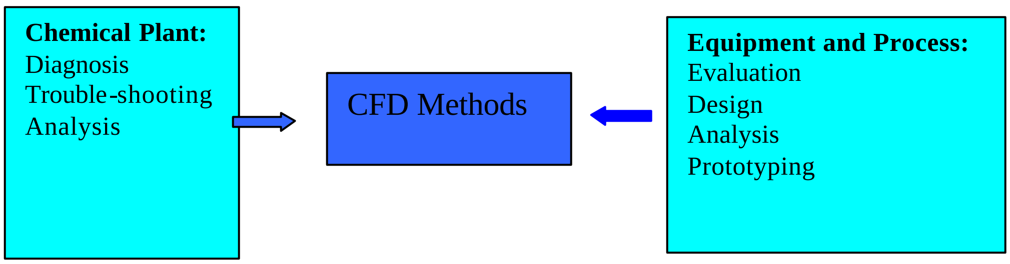

Figure 1: CFD in chemical processing.

CFD Methods:

Computational fluid dynamics (CFD) methods are based on first principles of mass, momentum and energy conservation. CFD methods involve the solution of conservation equations for mass, momentum and energy at thousands of locations within the flow domain. The details of these methods are described in references [2-3]. The computed solution provides flow variables such as velocity, pressure, temperature, density, concentration, etc. at thousands of locations within the domain.

CFD Applications in the Chemical Process Industries:

CFD applications to a number of unit operations and processes in the chemical process industries, oil and gas industry are described in references [4-11]. In general CFD methods are applied to understand the overall flow and heat transfer behavior. A typical study is aimed at comparing and evaluating designs or concepts. 'What-if' studies are performed to examine the influence of various parameters on flow behavior and hence performance. Unlike experimental methods, CFD provides full-field data. The impact of CFD on chemical process equipment is summarized in Table I.

Process Equipment	Impact of CFD
Mixing: Stirred tank reactors, static mixers, jet mixers, emulsification units.	• Examine performance of static mixers. • Optimize stirred tank performance. • Predict shear distribution in stirred tank reactor. • Scale-up/scale-down of reactors
Fluid Transport devices: Pumps, compressors, manifolds, headers, valves, flow distributors.	• Establish envelope of performance. • Ensure uniform flow distribution. • Minimize power requirements. • Identify and eliminate sources of erosion in transport of slurry.
Separation units: Cyclones, scrubbers, precipitators, centrifuges, gravity separators,	• Optimize and predict performance. • Take a 'look-inside' the process. • Evaluate design concepts.
Heat generation and heat transfer: Heat exchangers, boilers, furnaces, process heaters, burners.	• Minimize failure of heat-exchangers. • Control formation of pollutants. • Eliminate hot-spots in heaters. • Improve flame stability and burner efficiency. • Improved heat-recovery.
Reactors: Packed bed, bubble column, fluidized bed.	• Improved catalyst utilization. • Minimize waste. • Reduced operating costs.
Auxiliary processes: Filling, packing.	• Eliminate plugging, sloshing, spilling.

Table I: Impact of CFD on various processes in the chemical process industries.

CFD for separators: In the following study, CFD is applied to improve the performance of an electrostatic precipitator (ESP). The effect of distributor plate arrangement on flow uniformity in the diffuser section of an ESP is examined. The original design employs a grid-type distributor plate as shown in Figure 2a. As depicted in Figure 2b, the flow entering the diffuser is not uniformly distributed and continues as a jet in the core of the diffuser section. The effect of a grid employing splitter plates is examined. This configuration is shown in Figure 3a. The velocity field in the ESP, as depicted in Figure 3b is more uniform but the recirculation region is not entirely eliminated.

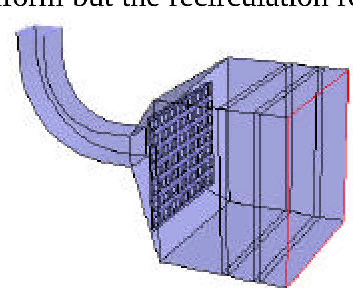

Figure 2a: Electro-static precipitator

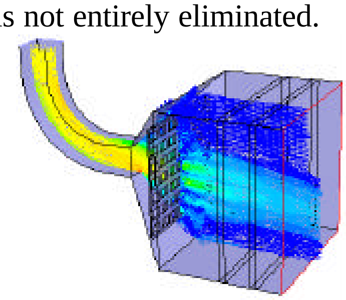

Figure 2b: Velocity field in precipitator

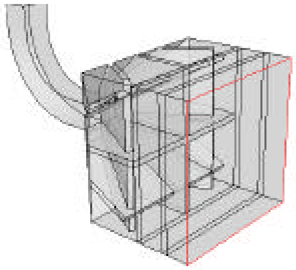

Figure 3a: Electro-static precipitator, modified configuration

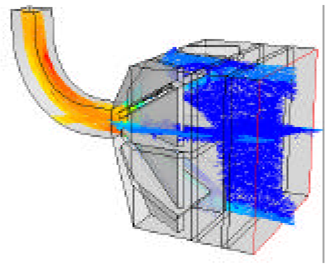

Figure 3b: Electro-static precipitator, modified configuration velocity field.

CFD for Dryers: Drying equipment is usually large and expensive. As a result, efficiency is an important factor that influences production and operation cost. In this section the benefits derived from CFD study of a spray dryer are discussed.

CFD is used to analyze the performance of an industrial spray dryer in advance of making major structural changes to the dryer. The risk of lost profit during changeover (especially if the improvement did not materialize) is minimized. CFD is applied to examine configuration changes and thus minimize risk and avoid unnecessary downtime during testing. The velocity distribution depicted in Figure 4 shows skewed flow. This is a result of uneven pressure distribution in the air dispersing head. CFD models are applied to determine optimum equipment configuration and process settings. CFD results can provide the necessary confidence that the proposed modifications will work before capital equipment is ordered and field-testing scheduled.

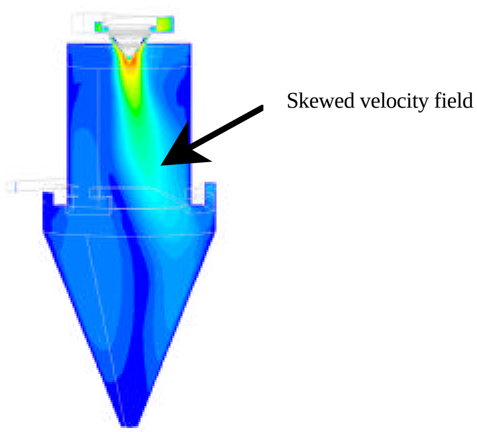

Figure 4: Spray dryer, velocity field

CFD for Heat generation and Heat Transfer Equipment: Heat transfer and power generation equipment is employed throughout a chemical processing plant. Failure of this equipment can lead to downtime and significant loss of revenue. Hence, it is essential for this equipment to perform as reliably as possible. Inefficiencies associated with heat transfer equipment directly influence production cost. Small increments in improved efficiency can result in significant reduction of operating cost and increased revenues. CFD techniques can provide an insight into the function of these devices and can help identify areas for improvement.

CFD methods are applied to eliminate tube-failure in a gas-fired boiler. The boiler is depicted in Figure 5a; the burner as shown in Figure 5b consists of a fuel lance. The oxidant is introduced through the annular space and passes through a set of swirl-vanes. The swirl imparted by the vanes stabilizes the flame. The temperature plot in Figure 5c depicts the high temperature region in the convective section of the furnace chamber. This is the region where boiler tubes are most likely to fail. The velocity field in Figure 5d depicts a low velocity region near the outer surface of the radiant section. However, the temperatures in this region are acceptable. Design changes to induce a more uniform temperature field in the convective section of the furnace were explored using CFD methods.

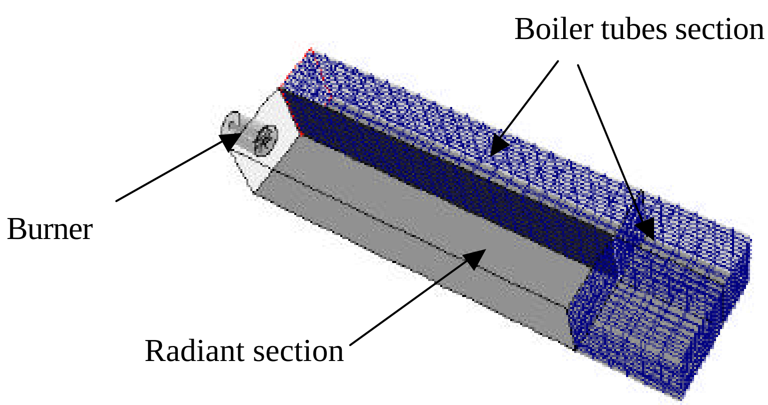

Figure 5a: Boiler layout.

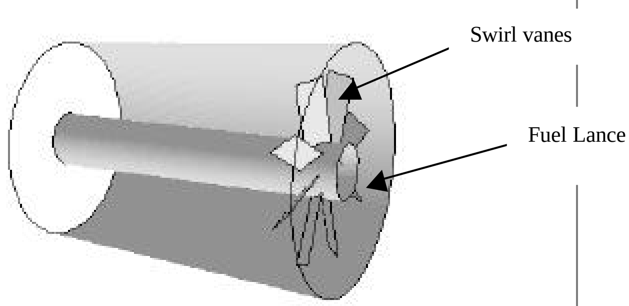

Figure 5b: Boiler configuration.

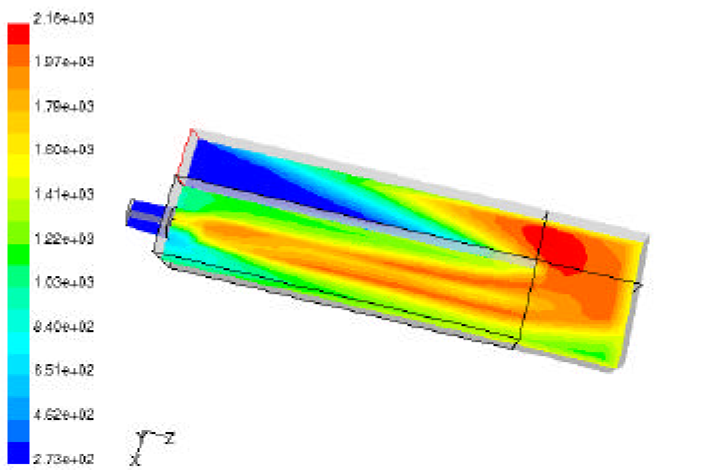

Figure 5c: Temperature distribution in boiler (temperatures in ^oK).

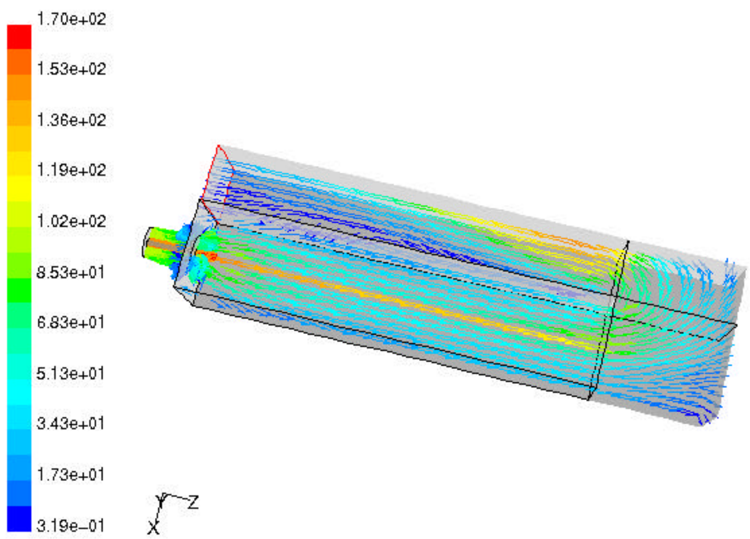

Figure 5d: Velocity distribution in boiler (velocity in m/sec)

Additional applications of CFD to processes and process equipment are described in references [4-11].

Conclusions:

Unit operations in chemical process industries handle large amounts of fluid, as a result, small increments in efficiency lead to large increments in product cost savings, CFD solutions can help accomplish this. The number of processes that can be improved with the aid of CFD techniques are many. Chemical process industries are now beginning to accept this technology; however, it is yet to be fully integrated. The potential for process improvements using CFD solutions is yet to be realized.

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