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Improving plant operations with control valve simulations

In today's business climate, where project budgets and schedules are under cost and time pressures (and where installed valve applications must perform reliably under increasingly severe conditions), valve simulations are enabling new capabilities. This article describes five case studies where a vendor is providing industrial plants and facilities with an array of valve solution simulations to eliminate the need for testing.

Why simulation? Valve testing ensures that valves meet the requirements of an application—as far as plant personnel can estimate. However, in some cases, conditions are not exactly as predicted, and the valve may not perform as expected. In such a case, plant personnel are faced with an expensive decision: Should the valve be removed and sent back to a lab for further testing, or is another solution available?

The alternate solution is simulation. With computational fluid dynamics (CFD), a simulation engineer can develop predictive, physics-based computational models to cover a wide range of tests and situations, including valve flow coefficients, multiphase applications, turbine bypass temperature sensor optimization, and installed valve troubleshooting, among others. With CFD, a simulation engineer can input the design of the valve in question, simulate the installed conditions, identify the problem and develop a solution.

By modeling existing process conditions, CFD helps designers formulate solutions to control valve issues such as buffeting, vibration, erosion and valve instability.

CFD at work. CFD simulation is already being used by most valve vendors for initial design (e.g., when engineers need to understand a valve's expected flow performance under certain conditions). While experienced valve designers typically have a sense for how the valve and trim geometries must be shaped to provide the desired flow performance, CFD provides insights and physics-based predictions of the expected performance. Physical flow testing has historically been used to determine valve performance, but CFD simulations are now commonly used to predict flow performance during the design process of new valves, either prior to, or in lieu of, physical flow testing.

Typically, a valve designer will create a valve, use simulation to evaluate concepts and refine the design (**FIG. 1**), and then have a valve cast. The new valve will then be subjected to flow lab testing. If the valve performs as expected, it can go into production. If not, testing will usually point out areas requiring modification. The valve design simulation model can also be used for future testing, including CFD simulation of valves installed in the field. It is crucial to validate CFD simulations against actual test results in a flow lab, and to involve experienced analysts in the simulation to assist in ensuring the quality of results.

Simulation experts apply best practices with quantified uncertainties developed using data procured in test facilities, coupled with field experience, to provide value in ways only simulation can provide. End-user collaboration is critical for identifying the pain points and understanding where simulation can be of service.

Some simulation capabilities include:

- Fluid dynamics analysis via simulation of capacity, choking, velocities and pressure profiles
- Validation through prototypes and production unit flow tests
- Structural checks using finite element analysis (FEA)
- Validation through digital image correlation and strain gauge hydro tests
- Thermal analysis via computational model thermal profiles
- Validation through prototypes and production unit process temperature tests
- Seismic analysis to computationally predict and exaggerate structural loads
- Validation through prototypes and production unit load tests.

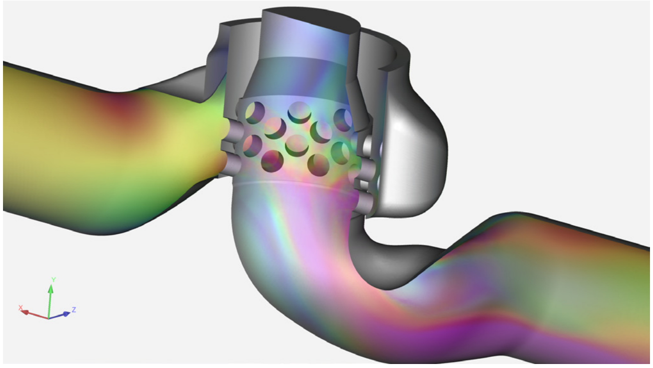

FIG. 1. Diagram depicting fluid flow distribution through a valve, as predicted with CFD.

FIG. 2. CFD simulations proved that this butterfly control valve[a] would pass enough flow for the OEM's turbine application.

Traditionally, CFD has only been used as an internal resource by valve vendors, primarily for new product development and testing, and has rarely been made available outside of a vendor's lab. However, some control valve vendors are now providing CFD simulation services to end users to help them cut costs, reduce downtime and make other operational improvements. The following are a few examples.

CFD replaces testing. A major original equipment manufacturer (OEM) of power plant turbines required flow capacity Cv validation on a 32-in. high-performance butterfly control valve[a] (**FIG. 2**) installed in a critical bypass application. The traditional solution would have been to physically flow test the valve, but this was deemed unacceptable because of increased costs and negative schedule impacts.

Instead, valve simulation engineers created a CFD model of the butterfly valve to simulate the Cv, then verified to the OEM through a report that the valve would perform as expected. The simulation provided a ±7% confidence band for all flow coefficients.

By using CFD as an acceptable alternative to physical flow testing, the turbine OEM saved more than $100,000, with no delivery schedule interruption.

Accommodating current installations. Thirty years ago, a refinery installed a severe-service (**FIG. 3**) control valve[b] in the non-preferred flow-up direction. The refinery was undergoing an expansion project where process conditions required a larger-capacity severe-service control valve. Refinery personnel wanted to replace the valve with another control valve due to its 30-plus yr of proven service; however, they realized that changing the piping to the preferred flow-down orientation would be too costly and would negatively impact the project schedule. The refinery wanted to keep the flow-up orientation, which led to sizing implications, since the valve sizing parameters were flow tested only in the flow-down orientation.

The service was too critical to size the valve by using the process of extrapolating valve sizing parameters to match the application. Instead, a CFD simulation was performed to predict valve flow coefficients and pressure drop ratio factors, allowing for accurate control valve sizing. The new valve was installed and is functioning as required in this severe-service application.

Put the temperature sensors where? CFD provides value in both front-end engineering design (FEED) and post-installation situations. This CFD application not only solved a problem, but it also provided a model for this end user's future FEED projects.

Turbine bypass is considered one of the most critical control valve applications in a power plant. Properly selected turbine bypass valves (**FIG. 4**) are important for keeping a turbine safe and for maintaining the overall power plant heat rate, a common measure of efficiency. In a bypass system, steam is de-superheated by creating a pressure drop, with a control valve used to add the proper amount of water to the steam.

CFD was used to predict the ideal location to install temperature transmitters, specifically where the added water is fully evaporated, and where temperature readings would be most accurate. With better-understood requirements for turbine bypass valve temperature transmitter locations, downstream straight-length piping requirements were reduced from those provided by the sizing tool. This cut installation cost and time.

An undersized actuator. A high-pressure injection pump recycle valve on an offshore platform in the North Sea was experiencing instability issues when trying to control a 3,700-psid seawater pressure drop. The solution for sizing this critical severe-service, multiphase fluid control valve was to utilize CFD to ensure that the control valve and the downstream pressure relief valve were sized correctly. For both valves, CFD simulations were used to predict valve Cv and pressure drop ratio factors, allowing for accurate sizing.

In addition, root cause analysis of an undersized actuator on the control valve was derived using both smart positioner online diagnostics and CFD simulation. This was accomplished without taking the valve apart and causing further interruptions. A new actuator was shipped and installed, solving the problem at minimal cost and disruption to existing operations.

Outside industry standards. The IEC 60534-2-1 control valve sizing standard covers most control valve applications. However, many applications fall outside its scope, such as outgassing and fluid flows composed of multiple phases.

An OEM for a refinery water treatment skid required CFD analysis on its severe-service, multiple-component fluid control valve application to ensure that the control valve was sized correctly. The OEM did not want an oversized valve because this would negatively affect the sizing of the downstream pressure relief valve. The high pressure drop and the presence of solids required a flow-down, severe-service control valve with erosion-resistant materials, including solid stellite trim with ceramic inserts, and an outlet liner extending beyond the valve outlet.

OEM process engineers provided full fluid composition data, enabling the valve simulation engineers to generate a CFD report and correctly size the control valve. Accurate CFD modeling (**FIG. 5**) mitigated the OEM's risk of under- or over-sizing these final control elements—thus providing confidence to the OEM's customer regarding the performance of due diligence for these critical skid components.

FIG. 3. A refinery installed a control valve[b] in the non-preferred direction, although it has been working well for more than 30 yr. A plant expansion requires a larger valve, with the same non-preferred flow-up orientation.

FIG. 4. View of a steam recycle valve.[c]

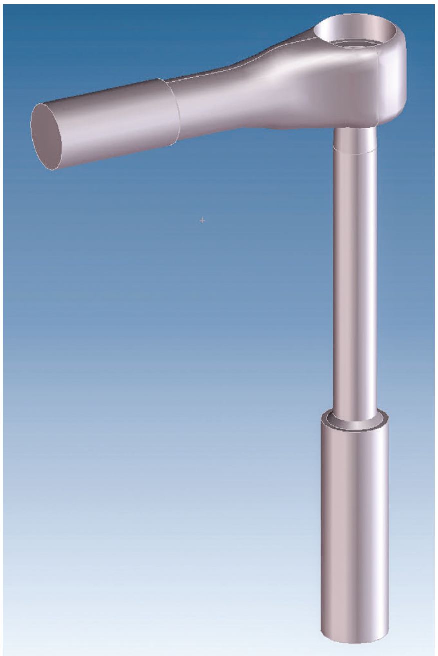

FIG. 5. Flow geometry used for CFD on a flow-down, severe-service control valve with an outlet liner.

Extensive expertise required. Almost anyone can acquire simulation software and create an attractive rainbow-hued image as in **FIG. 1,** but it takes an experienced valve designer to set boundary conditions, meshing and material properties to obtain results correlating well to testing.

This is especially the case with the specialized application of using CFD to replace valve testing, where non-expert analysts can create situations with serious consequences with respect to design decisions. For example, with some control valve designs, seemingly trivial changes to meshing inputs can result in unexpectedly large effects on valve capacity predictions. This sensitivity to small input changes is further magnified by the selection of, and coupling with, an appropriate turbulence model for massively separated and complex recirculating flows.

The proliferation of results generated by using non-validated CFD methodologies can have serious consequences on design decisions, which can, consequently, more than offset expected project schedules and cost benefits.

If non-validated CFD methodologies are used early in the design cycle, the expected benefits may not be realized due to unquantified or uncharacterized deficiencies in the method. This is especially applicable to the use of CFD analysis tools, which typically automatically apply modeling and meshing choices without any user involvement or awareness.

CFD simulations can provide insight and value, but not all CFD simulations are equal. End users must be certain that the valve vendor can back up simulations with test data from a flow lab, with experienced valve designers and applications engineers available to interpret results.

Takeaway. When a valve vendor designs a valve by using CFD, and tests the designs in a flow lab, it produces a software model that can be used to predict or diagnose problems with installed valves. CFD simulations are not only being used in new product development, but they are also being provided by valve vendors as a service to end users, thereby saving time and money when diagnosing problems with installed valves. HP

NOTES

[a] Fisher Model 8532 butterfly control valve
[b] Fisher Type 461 severe-service control valve
[c] Fisher Model TBX steam recycle valve

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