The flow distribution in a condensate demineralizer vessel of a nuclear power plant is studied using the computational fluid dynamics (CFD) approach. The model simulates the flow through the packed resin bed installed in the vessel as well as the exit of flow through the porous resin retention assembly at the bottom of the vessel. The computational model is subsequently revised to assess the impact of a proposed modification to the retention assembly to enhance drainage of the vessel and minimize unwanted resin separation during resin bed regeneration. The subject model has been developed using the ANSYS ICEM CFD meshing tool and the FLUENT 6.3 CFD software as well as associated postprocessing tools. Comparisons of flow patterns in the vessel resin beds prior to and with the modification demonstrate a sharp increase in the flow rate at the end walls of the vessel, thus resulting in accelerated depletion of resin in high-velocity areas and nonuniform consumption of resin inventory. The computational results are also compared with a theoretical analysis of the basic process.

I. INTRODUCTION

The heat transfer from the reactor primary loop to the secondary loop of a pressurized water reactor (PWR) nuclear power plant occurs in the steam generators (heat exchangers), which results in steam production. The steam is directed from the steam generators to the turbine that turns the generator to produce electrical power. Upon exiting the turbine, the low-quality steam is condensed, subcooled, and then returned to the steam generator where the cycle repeats. The secondary system chemistry is maintained within stringent limits so as to minimize material degradation (i.e., corrosion) due to the plate-out of various impurities, particularly in regions of high-quality (dry) steam in the steam generators. Purification or “polishing” of the return condensate is therefore essential to guarantee a high-quality feedwater to the steam generator and to reduce potential for component corrosion. This is conducted in a “condensate polisher service vessel” or “condensate demineralizer,” the flow through which is the focus of this paper. In particular, this paper concerns fluid mechanics of the polisher vessel at the Palo Verde Nuclear Generating Station (PVNGS), Arizona, in light of a management proposal for a design modification to improve its polishing efficiency.

The polisher vessel is filled with polymer resins that are used to remove contaminants via ion exchange so that the condensate is maintained at or near the properties of distilled water. The condensate demineralizer is a rubber-lined stainless steel–floored spherical chamber, containing a mixed-bed regenerative-type resin for ion exchange (polishing). The condensate enters the condensate demineralizer at ~347 kg/s (averaged rate) through condensate inlet (Fig. 1) and is uniformly distributed within...
the vessel by an inlet distributor. The condensate water passing through the resin is cleansed or “polished” in the resin bed via an ion-exchange mechanism. Specifically, as the solution passes through the resin, it comes in contact with exchange sites of the resin, thus trapping unwanted ions, resulting in water with low levels of dissolved material concentration. The treated water is filtered through a retention element assembly consisting of lateral porous pipes with R-grade Regimesh filters or screens that allow discharge of the polished flow while retaining resin in the polisher. The resin mixture is used until the resin bed is depleted, at which time the condensate demineralizer is removed from service. The retention elements take the form of a grid that fits to the size of the vessel floor (Fig. 2), and all are connected to a common condensate outlet pipe below. A plan view of the piping is shown in Fig. 3a, and design information of the condensate polisher vessel is provided in Table I.

Fig. 1. A cross section of the condensate polisher.

Fig. 2. (a) Inside image of the condensate polisher with residual on the floor and (b) schematic of water flow.
Upon depletion of the resin bed, the resin is recovered through a resin transfer outlet (Fig. 1). The vessel is then rinsed to remove the residual resin. The construction of the tank and the physical placement of the drain, however, do not provide for complete drainage of the rinse water. Consequently, as the new mixed resin is introduced into the vessel, unwanted resin separation occurs at the bottom due to the density difference between the cation and anion resin, wherein the denser cation resin settles to the bottom. Devoid of mixed resin at the bottom, the leftover regeneration chemicals—sulfate on the cation resin—are not cleaned up with the anion resin since there is none on the bottom. Thus, it reduces the efficiency and capacity of the resin bed.

To address this problem and permit complete drainage of the condensate demineralizer, physical modifications to the retention element assembly have been proposed by PVNGS engineering. The modifications require the removal of two resin retention elements (pipes) from the ends of the piping assembly, as shown in Fig. 3, and covering of the opening with a porous screen. This modification will allow water to completely drain from the vessel. Such a modification must be evaluated relative to the impact on the internal flow distribution and consequential impact on the resin bed consumption—and this need provides motivation for the present work. To this end, a systematic computational fluid dynamics (CFD) simulation on hydrodynamic impacts due to modification of end-screens of the resin retention grid was conducted at the request of PVNGS. Because of the expense and long time period required for conducting physical model tests, the PVNGS decided to base its decision largely on numerical simulation results and physical understanding and intuition.

Considering the complexity of geometry and hydrodynamics of condensate demineralizer flow, the investigation consisted of several interrelated studies: an initial analytical study of flow distribution of the as-built design, preparation of a geometric model for meshing, numerical simulation of flow in current and modified condensate demineralizer geometries, and comparison of resultant flow patterns between existing and modified geometries.

### II. MESH DESIGN

The condensate demineralizer vessel geometry was designed in SolidWorks 2007 software tool and then exported to ICEM CFD 10.0 tool to mesh the geometry. The resultant mesh was then exported to the FLUENT 6.3 solver for processing and postprocessing. The unstructured design approach using tetrahedral mesh structure was used for meshing with adaptive grid spacing for different locations of the flow. The ICEM CFD 10.0 Tetra works directly from the solid model surfaces and fills the volume with tetrahedral elements using the Octree approach. The ICEM CFD Tetra generates the volume mesh as well as the surface mesh on the object surfaces. The mesh generation tool was used and local
adaptive mesh refinements (more or less coarse) were made as necessary. Figure 4 shows the final mesh designs of various components of the condensate demineralizer.

III. FLUENT SOLVER

For the as-built design, a laminar flow calculation was conducted first to obtain an initial solution, and thereafter a turbulence model was introduced to compute the final as-built solution. A pressure-based segregated solver with an implicit solution approach is used to model the vessel flow because of the less restrictive requirements for memory and enhanced flexibility in the numerical solution.

The complete domain of the vessel is discretized into a finite set of control volumes or cells. The general transport equation for mass, momentum, and energy is applied to each cell and discretized.\textsuperscript{10,11} For a cell $P$, the transport equation is

$$\frac{\partial}{\partial t} \int_V \rho \phi \, dV + \oint_A \rho \phi \mathbf{v} \cdot dA = \oint_A \Gamma \nabla \phi \cdot dA + \oint_A S_\phi \, dV ,$$

where

- $\phi$ = any scalar variable
- $\mathbf{v}$ = velocity vector
- $dA$ = surface area vector
- $\Gamma$ = diffusion coefficient.

Fig. 4. Mesh design of various components of the condensate polisher vessel.
Each transport equation is discretized into an algebraic sum

\[
\frac{(\rho \phi_p)' - (\rho \phi_p)}{\Delta t} + \sum_{faces} \rho_i \phi_f v_f A_f = 0
\]

\[
= \sum_{faces} \Gamma_f (\nabla \phi)_{f} \cdot A_f + S_{\phi} \Delta V .
\]

Note that \( \phi \) equals unity for continuity, \( u \) represents the x-direction momentum, \( v \) the y-direction momentum, and \( h \) the total energy in \( P \). The discretization and linearization of governing equations produce a system of equations for the dependent variables for each computational cell \( P \). Therefore, the resultant linear system is solved to yield an updated flow-field solution. Various interpolation schemes are available to solve for the convection term in the discretized equations. For the condensate demineralizer vessel flow, a second-order upwind interpolation scheme is preferred because of less diffusive errors, large stability bounds, and better numerical resolution. It offers second-order accuracy with larger “stencil” size, especially when the flow is not aligned with the grid.

**IV. NUMERICAL MODELING**

The packed resin bed has been modeled as a porous medium consisting of an interconnected three-dimensional solid matrix with a highly webbed network of pores through which the fluid can flow. A porous media model incorporates an empirically determined flow resistance in the model defined as “porous” region. Therefore, the porous media adds a momentum sink to the governing equations and is modeled by adding momentum source term to standard fluid flow equations.\(^{12}\) The Darcy term is composed of two parts: a viscous loss term and an inertial loss term,\(^{13,14}\) namely,

\[
S_i = -\left( 3 \sum_{j=1}^{3} D_{ij} \mu u_j + \sum_{j=1}^{3} C_{ij} \frac{1}{2} \rho |u| u_j \right),
\]

where

- \( S_i \) = source term for the \( i \)’th \((x, y,\text{ or } z)\) momentum equation
- \( |u| = \text{magnitude of the velocity} \)
- \( D, C = \text{prescribed matrices.} \)

These momentum sinks contribute to the pressure gradient in the porous cell, creating a pressure drop that is proportional to either the fluid velocity or velocity squared in the cell.

A one-dimensional simplification of the porous media model, called a “porous jump,” can be used to model a thin membrane with known velocity and pressure-drop characteristics.\(^{12}\) This porous jump model is applied to a face zone. To simplify the analysis, the porous jump model was used instead of a full porous media model. This approach was taken to simplify modeling of the interface between the porous resin bed and the resin retention screens of condensate demineralizer. This modification significantly improved model convergence in this region. For the case of simple homogeneous porous media, a one-dimensional form of the Darcy equation can be written as

\[
S_c = -\left( \frac{\mu}{\alpha} u + C_2 \frac{1}{2} \rho |u| u \right),
\]

where

- \( \alpha = \text{permeability of the medium} \)
- \( C_2 = \text{pressure drop coefficient} \)
- \( \rho = \text{fluid density} \)
- \( \mu = \text{fluid viscosity} \)
- \( u = \text{velocity component normal to the porous face} \)

The resultant momentum equations are

\[
\rho u \frac{\partial u}{\partial x} + \rho v \frac{\partial u}{\partial y} = -\frac{\partial p}{\partial x} + \mu \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) + S_x
\]

and

\[
S_x = -\left( \frac{\mu}{\alpha} u + C_2 \frac{1}{2} \rho |u| u \right),
\]

where the porous medium is assumed isotropic. The resulting momentum sink contributes to the pressure gradient in the porous cell, creating a pressure drop proportional to the fluid velocity (or velocity squared) in the cell,

\[
\Delta p = -\left( \frac{\mu}{\alpha} u + C_2 \frac{1}{2} \rho u^2 \right) \Delta m .
\]

When defining the boundary conditions, the face permeability \( \alpha \), the thickness of the medium \( \Delta m \), and the pressure jump coefficient \( C_2 \) need to be specified. For laminar flow through porous media, the pressure drop is typically proportional to the velocity, and the constant \( C_2 \) can be considered zero. In the absence of convective acceleration and diffusion, the porous media model reduces to Darcy’s law,

\[
\nabla p = -\frac{\mu}{\alpha} u
\]

or

\[
\nabla p_x = \sum_{j=1}^{3} \frac{\mu}{\alpha_{sj}} u_j \Delta n_x .
\]
Here, the thickness of the medium ($\Delta n_x, \Delta n_y, \Delta n_z$) is consistent with the thickness of the porous region in the model.

In the present case, the condensate demineralizer processes a total flow rate of $\sim 347$ kg/s. The flow is uniformly distributed at the inlet. The total pressure at the inlet is adjusted in the model to achieve the velocity needed to provide the prescribed mass flux. The resin retention element screen is estimated to have permeability $\alpha = 2.8 \times 10^{-8}$ m$^2$ using an empirical relation.\(^{15}\) The water flows through these porous screens into the individual retention pipes, and then is routed to the central discharge outlet located at the bottom of the vessel (Fig. 1). The model outlet boundary condition typically requires specification of static (gauge) pressure at the outlet boundary, which was not followed in the present study since the pressure and other flow quantities were extrapolated from the interior flow.

The numerical investigation of flow through the polisher includes turbulent flow exterior to the porous screens,\(^{16–18}\) where a turbulence model needed to be employed. For flow with complex geometries, it is better to specify the initial values in terms of turbulence intensity and hydraulic diameter, as discussed later. Overall, when the initial conditions supplied are in the proximity of an exact solution, the computations converge quickly. As such, the simulation was run as a laminar case for the first 50 iterations to get an initial solution, and thereafter the turbulence model was applied for the outer region. Thus, the laminar case was used as a setup for the final run for the model.

The Reynolds-averaged Navier-Stokes two-equation $k$-$\varepsilon$ turbulence model was used considering that it applies to an extensive range of turbulent conditions widely used in engineering applications.\(^{19}\) This method uses two separate transport equations, which allow turbulent velocity and length scales to be independently determined. The turbulent kinetic energy $k$ and its rate of dissipation $\varepsilon$ are obtained from the following transport equations:

$$\frac{\partial}{\partial t} (\rho k) + \frac{\partial}{\partial x_i} (\rho k u_i) = \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] + G_k + G_b - \rho \varepsilon - Y_M + S_k \quad (10)$$

and

$$\frac{\partial}{\partial t} (\rho \varepsilon) + \frac{\partial}{\partial x_i} (\rho \varepsilon u_i) = \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu_t}{\sigma_\varepsilon} \right) \frac{\partial \varepsilon}{\partial x_j} \right] + C_{1\varepsilon} \frac{\varepsilon}{k} (G_k + C_{3\varepsilon} G_b) - C_{2\varepsilon} \frac{\varepsilon^2}{k} + S_\varepsilon \quad (11)$$

where

- $G_k$ = generation of turbulent kinetic energy due to mean velocity gradients
- $G_b$ = generation of turbulence kinetic energy due to buoancy
- $Y_M$ = contribution of fluctuating dilatation in compressible turbulence to the overall dissipation rate
- $S_k, S_\varepsilon$ = user-defined source terms.

The model constants $C_{1\varepsilon}, C_{2\varepsilon}, C_\mu, \sigma_k, \sigma_\varepsilon$ have the following default values:

$$C_{1\varepsilon} = 1.44, \quad C_{2\varepsilon} = 1.92, \quad C_\mu = 0.09,$$

$$\sigma_k = 1.0, \quad \sigma_\varepsilon = 1.3.$$  

Boundary conditions for turbulence intensity and hydraulic diameter were selected as they are ideally suited for internal (duct and pipe) flows. The turbulence intensity $I$ is defined as the ratio of the $rms$ velocity fluctuations ($\overline{u'^2}$) to the mean flow velocity $\overline{u}$. Ideally, a good estimate of the turbulence intensity at the inlet boundary can be obtained using the empirical relation

$$I = \frac{\overline{u'^2}}{\overline{u}} = 0.16(Re_{D_b})^{-1/8}, \quad (12)$$

where

$$Re_{D_b} = \frac{QD_b}{\nu A},$$

$Q$ = mass flow rate through inlet
$D_b$ = hydraulic diameter of the inlet
$\nu = \mu/\rho$ = kinematic viscosity.

An $I \equiv 3.68\%$ was calculated for the present case based on $D_b = 3.5$ m.

Upon completion of the base case simulations for the as-built demineralizer configuration, the model was modified to assess the impact on the resin bed flow structure of the structural modification (i.e., the removal of terminal retention elements and shrouding of the branch opening with a piece of screen to contain the resin). With all other analysis assumptions remaining constant, the flow conditions were then compared for the modified and unmodified cases.

V. RESULTS AND ANALYSIS

This section presents the results of the condensate demineralizer vessel simulations, before and after the proposed modification. The latter removes the terminal retention elements on both ends of the assembly and
install a block of screen material at these locations to preclude resin loss. As mentioned, the initial modeling for unmodified geometry was done with laminar flow equations. The turbulence modeling was subsequently included to obtain a steady solution.

Figure 5 presents the velocity magnitude for a cross section through the pipes. The figure demonstrates that the flow increases as it approaches outlet hub in the center. This is physically plausible, given that the velocity $u_p$ at a distance $l$ from the end of a porous pipe of radius $r_p$ is given by

$$u_p(l) = \frac{2}{r} \int_0^l u(x') \, dx'$$

where $x'$ is measured from an end of the porous pipes. As water from both halves of a retention element approaches the center, the flows can impinge, generating turbulence and rapid dissipation when the flows merge. Another possibility is the flow deflection and formation of a vertical flow. These scenarios are shown in Fig. 5b (i) and (ii).

The modification consists of the removal of two end pipes and trimming the vertical extent of the exit pipes to enable draining of water left at the bottom of the polisher during resin replenishment. This is possible because of the lower height of the new exit in comparison to other pipes. As noted before, the calculations were repeated with the modified geometry. Figure 5 shows velocity vectors through porous pipes and the modified end opening. Note that the velocity through the end hub is much higher.

VI. THEORETICAL CONSIDERATIONS

In this section, a theoretical analysis is developed to serve as the basis of the numerical evaluation of the flow through piping network and for the modified network. Assume $x$ is now defined as in Fig. 8.

At any $x$, the axial flow velocity is $u_p(x)$, and the porous suction velocity is $u_n$. The momentum balance for a fluid volume $(dx \times A)$, where $A = \pi r_p^2$ is the cross-sectional area of the pipe with radius $r_p$, can be written as

$$-\frac{1}{\rho} \frac{\partial p}{\partial x} = \frac{\partial u_n^2}{\partial x} + \frac{2}{r_p} \frac{2}{r_p}$$

where $p(x)$ is the pressure. A simple equation for suction velocity is

$$u_n = \left( \frac{p_v - p}{t} \right) \frac{\alpha}{\mu}$$

where

- $p_v =$ vessel pressure
- $t =$ screen thickness.

Mass continuity implies that

$$\frac{\partial u_p}{\partial x} = \frac{2u_n}{r_p}.$$ 

Solving the above equations and integrating for $u_p$ from $x = 0$ to $x$ gives

$$\frac{u_{trp}}{\alpha} \left( \frac{\partial u_p}{\partial x} \right) - \frac{u_{trp}}{\alpha} \left( \frac{\partial u_p}{\partial x} \right) = u_p^2(x).$$
Defining
\[
a^2 = \frac{vtr_p \left( \frac{\partial u_p}{\partial x} \right)}{\alpha}, \quad b = \frac{a}{vtr},
\]
and integrating Eq. (17), the velocity at the intersection of the drum and pipe can be written as
\[
u_{p0} = a \tan(abL) ,
\]
where \(L\) is the pipe length. Note that \((\partial u_p/\partial x)_0\) is the boundary condition related to the suction velocity at \(x = 0\), and the overall pressure drop from the vessel into the exit drum is \(\Delta p_0 = (p_v - p_e)\), which can be evaluated using Eq. (17) by setting \(x = L\) and using Eq. (15) as

Fig. 6. Pathlines of tagged particles: (a) original geometry and (b) modified geometry configurations.

Fig. 7. Mass flux through each exit pipe: (a) original and (b) modified configurations.

Fig. 8. A schematic of a single exit pipe configuration.
Thus, we obtain

$$\left( \frac{\partial p}{\partial x} \right)_0 = \left( \frac{\Delta p_0}{\rho} - u_{p_0}^2 \right) \frac{\alpha}{vtr} ,$$

and using Eq. (18),

$$u_{p_0} = \left( \frac{\Delta p_0}{\rho} - u_{p_0}^2 \right)^{1/2} \tan \left[ \left( \frac{\alpha L}{vtr} \right) \left( \frac{\Delta p_0}{\rho} - u_{p_0}^2 \right)^{1/2} \right] .$$

Note that the volume flux in any drum of the original configuration can be obtained as 2(\pi r_p^2)u_{p_0}. If the volume flow rate through the drum opening after removing the two terminal retention elements is to be the same as that corresponding to Eq. (21), then its equivalent mesh thickness \( t_m \) must be given by Eq. (23).

From Eq. (19),

$$u_n = \frac{\Delta p_0 \alpha}{t_m \mu} \tag{22a}$$

or

$$\frac{\Delta p_0 \alpha}{t_m \mu} \pi r_m^2 = 2\pi r_p^2 u_{p_0} , \tag{22b}$$

where \( r_m \) is the drum diameter (Fig. 9), thus yielding

$$t_m = \frac{\Delta p_0 \alpha}{2\mu v} \left( \frac{r_m}{r_p} \right) \frac{1}{u_{p_0}} , \tag{23}$$

where \( u_{p_0} \) is determined by Eq. (21). If one were to maintain a screen thickness [Eq. (23)] calculated and based on independent parameters, then an approximately uniform volume flow rate can be expected through all drums (with or without modification). However, this does not guarantee the same flow distribution between the two cases. It is more likely that the flow velocities will be unacceptably high over the modified drums, given that they act as a flow sink.

In the physical condensate demineralizer, the pressure distribution in the vessel is determined by the condensate outlet vessel pressure, which, in turn, is determined by the external suction pressure. However, in the present simulation, the outlet pressure is extrapolated from the interior flow domain and the inlet pressure is derived from the inlet velocity. If the flow rates are equal after the outer retention elements are removed and replaced with the mesh screens, it follows that the vessel pressure drop for the modified system is approximately equal to that of the unmodified vessel \( \Delta p_0 \). From Eq. (23), \( t_m \) can be calculated with \( \Delta p_0 \) equal to the unmodified geometry case pressure drop across pipes. The values used in the calculation are \( \Delta p_0 = 33000 \text{ Pa} \) across unmodified pipes of case 1, \( r_m = 0.0782 \text{ m} \) drum radius, \( r = 0.0318 \text{ m} \) porous pipe radius, and \( u_{p_0} = 8.4 \text{ m/s} \) velocity achieved in the pipes before it is sucked by the outlets.

As mentioned above, Fig. 9a presents the results of the computational case in which \( P_{outlet} \) is calculated using the pressure outlet boundary conditions. For Fig. 9b, the simulation is run with the same mesh screen thickness as that used for pipes and \( P_{outlet} \). Here, \( P_{outlet} \) is lower than \( P_{outlet} \) since there is a lower resistance. In Fig. 9c, a thick mesh screen of thickness \( t_m \) is used to approximate the overall losses that the outlet pressure for modified geometry is expected to be close to the unmodified case.

According to Eq. (23), the calculated thickness is \( t_m = 33 \text{ cm} \). This mesh thickness will produce the same effect on the overall pressure drop as in the actual unmodified geometry. In addition, an approximately equal...

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**Fig. 9.** Schematic for three different exit configuration cases: (a) case 1: original geometry with actual and computational case; (b) case 2: modified geometry with similar mesh screen as the pipes; and (c) case 3: modified geometry with a mesh screen of thickness \( t_m \).
volume flow rate can be expected through all drums (piped and modified). It is emphasized, however, that even with the same net flow through the demineralizer, the flow distribution inside the resin bed can be very different, with markedly higher velocities in certain locations, resulting in polishing inefficiencies and nonuniform exhaustion of resin.

**VII. VALIDATION AND CONVERGENCE**

The approach of using a laminar flow calculation as an initial setup followed by introduction of turbulence calculations reduced the computational time substantially and resulted in quick convergence. The velocity and turbulence residuals converged to approximately $10^{-6}$ and the continuity equation to $10^{-3}$. Thus, all discrete equations for continuity, momentum, and energy were satisfied within the specified tolerances. Moreover, the mass flow rate also stabilized at 347 kg/s, confirming a high-fidelity mass balance between inlet and outlet of the vessel.

As with all numerical evaluations involving turbulent flow, the fidelity of the results is to be considered with circumspection. The results are dependent on proper geometrical construction and appropriate grid type and size. To this end, the discretization error is of most concern to the production of a valid CFD model because it is dependent on the quality of the grid. It is often difficult to precisely gauge the relationship between the quality of the grid and the accuracy of the solution prior to the simulation. There is also a significant source of uncertainty in permeability calculations since it was evaluated using the empirical relation.

The quality of the results is further dependent on proper selection of initial and boundary conditions and the choice of closure models (i.e., turbulence). Usage errors increase with the increase of options available for a CFD simulation. However, they are minimized through proper understanding and cumulative experience. It is therefore prudent to compare measurements from the prototype with CFD simulations to validate the latter, but the plant is sparsely instrumented and no direct measurements are available from within the polisher vessel to evaluate the CFD model used. The general observations at PVNGS with the unmodified geometry, however, provide a reasonable physical understanding of the flow expected in the as-built facility, especially with regard to resin depletion patterns. The trends of computations were consistent with such experiences, and hence it was concluded that the computations are sufficiently reliable for decision making.

**VIII. CONCLUSIONS**

This work represents a theoretical and computational study of flow patterns in a condensate demineralizer (polisher) vessel of the PVNGS prior to and after a proposed engineering modification. The modification was extremely costly and required a priori feasibility assessment. The scope of study necessitated consideration of only a section of the condensate polisher vessel. The FLUENT CFD software was employed, and the results demonstrate a drastic change in internal flow patterns due to the removal of resin retention screen elements from both ends of the pipe network, which was the proposed modification. The open holes created in the hub where the retention elements were removed were also to be capped by porous screens to prevent the washout of resin. The computations show that the flow is locally amplified at the screen removal sites, given the local reduction of the net flow resistance in the area due to reduction of screen area due to element removal. Nevertheless, there are no significant differences in flow patterns in the middle section of the condensate demineralizer vessel. Physical considerations indicate that even if the open holes are capped with thicker screens than elsewhere to have the same pressure drop along the screen network, the flow distribution is still undesirable because of the flow amplification near the modified exit. This caused increased exhaustion of resin at flow amplification sites, thus reducing the effectiveness of the resin bed.

Based on the computations, analytical model, and physical arguments, the PVNGS was advised that the proposed modification will result in undesirable changes in the local flow rates in and around the modified region of the retention element assembly and hence nonuniform resin exhaustion. Consequently, the PVNGS engineers decided against the plant modification, and the management concurred with their recommendation.

**REFERENCES**


