ABSTRACT

Liquid seals creating high pressure drop and valves cavitating less intensively even at low flow rates are very essential in several critical applications like nuclear reactors, cryogenic engines and turbomachines. This research work investigates the effects of implementing newer labyrinth profiles on existing annular seals and conical valves towards finding better performing designs. The premier performance parameters for the seal and valve are the pressure drop ratio and vapour volume fraction. The objectives and constraints worked out from studying typical applications follow:

1. To develop newer labyrinth seals having a narrow annular gap of not less than 0.2 mm capable of achieving a high pressure drop ratio ($P_r$) of 10 or above at a low rated leakage flow of 2.5 m$^3$/h of water at 70°C. The seal should have a minimum length of 120 mm with any increase to this value stipulated to be as small as possible. The level of cavitation over the seal length should not be prohibitive.

2. To test a labyrinth-added design of a 24 mm size conical valve body on its ability to exhibit comparatively reduced vapour volume fraction for water entering the valve at a static pressure of 5 bar(g) at various valve open positions.

Research is necessitated because of the inability of the existing seals and conical valves in meeting the high targets under stiffly imposed conditions. To begin with the pressure drop characteristics of straight annular seals are investigated theoretically and numerically using an in-house Finite Element Analysis (FEA) code and a commercial Computational Fluid Dynamics (CFD) code Fluent. The studies clearly show that even the highest $P_r$ value that would occur at a seal length of 120 mm and radial clearance of 0.2 mm would be just below one.

Since labyrinths can bring in more flow resistance, the straight annular seal is first incorporated with circular-grooved labyrinth cavities having square and triangular
cross sections. Liquid flow through labyrinth seals is so complex that exact analytical solutions are unavailable. Extensive computer simulations and experiments are needed to resolve this challenging situation.

Several Circular-grooved Square cavity Labyrinth Seals (CSLS) and Circular-grooved Triangular cavity Labyrinth Seals (CTLS) of 120 mm seal length and 0.5 mm radial clearance having different cavity sizes/pitches are analysed using FEA/Fluent CFD codes and experiments. The simulation results are in close agreement with experimental values. Two different semi theoretical-semi experimental models; one each for CSLS and CTLS and employing three new terms to determine $P_r$ across the seals are formulated. The same in association with an Artificial Neural Network (ANN) model leads to a new methodology in the optimisation of these seals. The rated flow $P_r$ value of 1.85 for the optimal CTLS is better than that of the optimal CSLS.

Later, two different Circular-grooved Curved cavity Labyrinth Seals (CCLS) are developed using visualisation tests and parametric CFD analysis. The better of the two has rated flow $P_r$ value of 2.69. A Sinusoidal-grooved Triangular cavity Labyrinth Seal (STLS) is tested to have a rated flow $P_r$ value of 2.92. However, fabrication of the sinusoidal-grooved profiles is too complicated and costly. Hence investigations are diverted on to helical-grooved labyrinth Seals. Helical-grooved Square cavity Labyrinth Seals (HSLS) are found to be clearly better than their circular-grooved counterparts. The HSLS profile is optimised by another newer approach through a surrogacy based Genetic Algorithm (GA) model employing commercial codes. The optimal HSLS profile has a rated flow $P_r$ value of 2.58.

Investigations indicate a Helical-grooved Triangular cavity Labyrinth Seal (HTLS) to be just as good as the tested STLS. CFD analyses and experiments are carried out on various configurations of Helical-grooved Curved cavity Labyrinth Seal (HCLS). The best of them having a length of 200 mm and radial clearance of 0.3 mm
has an experimental rated flow $P$, just in excess of the target.

CFD cavitation analyses are carried out on helical-grooved square, triangular and curved cavity labyrinth seals. These studies illustrate the ability of the labyrinths in effectively and uniformly decreasing high pressures at low levels of vapour volume fraction. This inspired the machining of truncated rectangle shaped labyrinth cavities on the body of a Conventional Conical Valve (CCV) leading to a Labyrinth Conical Valve (LCV) intended to alleviate detrimental cavitation.

Computer simulation of the discharge and cavitation characteristics of CCV and LCV obtained using Fluent code at valve gaps ranging from 0.1 mm to 0.6 mm reveals that LCV is less cavitating than CCV at the same values of valve gap and discharge. Experiments on valves closely validated CFD discharge predictions. But, the cavitation intensities of the two valves are indistinguishable in experimental visual observation. Hence novel methods based on Digital Image Processing (DIP) and bacterial tests are invoked. These methods effectively confirmed that LCV is less cavitating than CCV.