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FLOW MALDISTRIBUTION IN HEAT EXCHANGERS: A REVIEW OF THE DIFFERENT TYPES

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ABSTRACT

The many kinds of inequalities and their causes are explored. Wherever feasible, methods for preventing or resolving the issue are provided. While the performance reduction is usually minor, the accompanying mechanical issues may be quite serious. The prefix mal denotes anything that is faulty or bad, thus the meaning of the word maldistribution is determined on how distribution is defined. How is uniform defined in the context of a comparison to a uniform distribution? A uniform distribution of a tube-side flow through a bundle of tubes may imply an equal quantity of fluid in each tube or that each fluid particle has an equal residence time in each tube (this would be "plug" flow). The fluid may, however, flow at the same rate (as is often assumed) or at various speeds. Because the local velocities change as the fluid travels through the bundle, defining uniform or continuous flow throughout a bundle of tubes becomes more difficult depending on where the reference flow region is situated. Other variables that influence the "distribution" of flow inside the bundle include bypassing and leakages in shell-and-tube exchangers.

KEYWORDS: *Fluid Flow, Heat Exchangers, Heat Transfer, Maldistribution, Uniform Distribution.*

1. INTRODUCTION

Other maldistributions are produced by the heat transfer process itself, such as viscous flow coolers or thermos acoustic oscillations, while others are induced by fabrication circumstances, such as mechanical design or manufacturing tolerances. The degree of these maldistribution impacts on exchanger heat transfer capacity, operational control, and potential mechanical damage is determined by the kind of maldistribution, as well as the exchanger design and secondary fluid flows, temperatures, and heat transfer coefficients[1]. While some instances of maldistribution have minimal impact on exchanger function, others cause substantial performance loss and/or mechanical failure[2].The effects of maldistribution on heat exchanger performance are examined after these different kinds of maldistribution are described in greater depth below.

Maldistribution in exchangers can be caused by a variety of factors, including:

- Mechanical causes such as header and inlet duct design influencing flow distribution, or manufacturing tolerances affecting the size of flow passages in compact-type exchangers;
- Self-induced maldistribution caused by the heat transfer process itself, such as the "freezing" effect in viscous flow coolant.

The velocity distribution reaching the face of the tube bundle or regenerator cores is substantially affected by the configuration of the headers and input ducts[3].A design for a shell-and-tube exchanger's particular situation of a minimal hold-up and uniform distribution header. Regenerator header designs are often complex by different space constraints, and can grow very intricate. Inlet axial nozzles, such as the ones illustrated, are common in shell-and-tube exchangers. This intake jet stream may be broken up by placing an impingement baffle halfway up the tube sheet[4].

The barrier should be perforated to prevent the tubes behind it from being "starved." An exchanger with a radial nozzle is thought to minimize jet impingement and provide a uniform distribution, however there is no evidence to support this theory[5]. Due to space constraints, the overall direction of fluid flow may not be in line with the exchanger flow channels. If the bundle depths are big enough, the linked flow pathways inside the tube bundle tend to smooth out non-uniform flow 'fields from outside the tube bundles. Shallow bundles, such as those employed in air coolers, have minimal impact on the velocity profile of the input stream. A clearance exists between the shell and the bundle's outer tubes in shell-and-tube exchangers[6]. This flow route has a lower resistance to flow than the bundle for segmentally baffled exchangers, thus a substantial quantity of fluid escapes the heating surface. There are also leakage routes between the tubes and the baffle (the "A" stream) and the baffle and the shell (the "E" stream).

Because the baffle-shell leakage skips the heating surfaces, it has a considerable impact on heat transfer, while the tube-baffle leakage streams come into contact with the heating surfaces and therefore have a moderate or perhaps negligible effect on heat transfer. Because of the spacing requirements for pass partition plates for multipass exchangers, there may be additional lanes inside the bundle. If these lanes (the "F" stream) are oriented in the cross-flow direction, they result in a partial bypass[7]. The bypass and leakage streams decrease flow through the tube bundle, lowering the total heat transfer coefficient; more importantly, the "slow" stream's greater fluid temperature change lowers the effective temperature differential inside the tube bundle. Before leaving the exchanger, the bypass and leakage streams, which are at different temperatures, mix with the bundle stream, and it is the mixed discharge temperature that is monitored and utilized to calculate the total temperature differential.

The first to identify and describe these different streams for shell-and-tube exchangers, as well as develop a technique for calculating the various stream flow rates using a pressure-balance calculation. on the different regions of bypass and leakage[8]. The design techniques utilized external measured temperatures to calculate the total temperature differential, as well as its correction factors if multipass, while creating the various weighting factors associated with each stream. As a result of the impact of these bypassing streams on the effective temperature differential, the weighting variables contain an inaccuracy. The possibility of temperature difference error has long been known, but it has never been used to correct experimental data; nevertheless, certain contemporary design techniques allow for an empirically determined adjustment.

For a given amount of p and R, the impact of the number of baffles and leakage ratios on F.Each baffle pass was believed to have perfect mixing; this may not be the case in the exchanger. It's possible to account for incomplete mixing by giving a mixing efficiency factor to each baffle pass. In any event, the stated inaccuracy is substantial for many exchangers. When the number of baffle passes is less than infinity, the usage of existing F correction charts, or their corresponding charts such as e-NTU, or J-P, must be considered as having some inaccuracy (the impact of the number of baffle passes is addressed below). Maldistribution takes place in the shell entrance (and exit) baffle spaces. Because of the nozzles' manufacturing constraints, the baffle spacing is often larger than the center spacing. Furthermore, since the tube sheets have no A or E leakage streams, the leaking pattern is unique. The direction of the baffle cut with relation to the nozzle axis may also cause different degrees of maldistribution in segmental baffling.

Depending on the segmental baffle direction and whether they are single or double segmental, end zones may have various flow patterns[9]. The tube sites where tube vibrations occur are likewise affected by these flow patterns. The Argonne National Laboratory is researching the impact of baffle types, tube placements, and other factors on tube vibrations. Because of their greater relative length, end gaps in short exchangers may be extremely harmful. Despite the fact that the disk-and-donut kind of baffle is seldom utilized, its apparent ratio of heat transfer coefficient per unit pressure drop much surpasses that of segmental baffles. Regenerators are often built for high NTU and therefore have a large area-to-volume ratio, necessitating construction with tiny flow channels[10].

2. DISCUSSION

Mechanical fabrication tolerances have a significant impact on the channel diameters and, as a result, the flow distribution. In addition, laminar flows are common in narrow passageways. The issue of determining tolerance limits for these small surfaces has received a lot of attention. In comparison to anticipated values for ideally sized channels, these studies looked at the impact of channel size variations on heat transfer coefficients and friction factors. If the test unit is typical of the production units, the j and f factors obtained experimentally will account for manufacturing tolerances.

Showed how flow maldistribution causes much more performance degradation. On both the air and gas sides, they measured the flow distribution approaching the core. Then, by altering the head designs, they were able to optimize the flow distribution and achieve substantial performance gains. They demonstrated that a significant portion of the improvement was attributable to the initial mismatch of the maldistributions; that is, the surface exposed to high air velocity would be exposed to low gas velocity, resulting in an imbalance of heat capacity fluxes. The impact of a heat capacity flow mismatch. The effects of carryover, longitudinal and transverse wall conduction, and fluid bypass owing to leakage are all factors to consider while designing rotary regenerators. Some clearances or, when they are employed for flow control, orifice diameters are also affected by wear or erosion.

A shallow tube bank and a wide face area are characteristic features of air-cooled heat exchangers. A comprehensive study of the impact of flow nonuniformity on the thermal performance of small heat exchangers, covering both parallel and cross-flow units. These articles deal with unmixed fluids on both sides of single-pass cross-flow exchangers. The loss in thermal performance owing to conduction due to temperature gradients in the walls, which may be significant in compact exchangers with large gradients. He then went on to look at the effects of non-uniform flow, and ultimately conduction and non-uniform flow on both sides. All of these studies cover a broad range of factors, and for some ranges and combinations of variables, the loss in thermal performance becomes substantial.

For refrigeration condensers and evaporators, air flow maldistribution, i.e., constant refrigerant temperature and coefficient. Different patterns such as linear, parabolic, step gradients, and random distribution in face velocities were compared for various degrees of flow maldistribution. The step gradient had the largest impact on the decrease of thermal performance. For in-line finned tube bundles, the impact of the bypass stream that runs through the fin tips. Before a unique relationship can be established between this flow nonuniformity factor and the deterioration of the thermal performance of a single-pass cross-flow heat exchanger for many two-dimensional flow no uniformities, it is necessary to develop a method that can be used to predict the deterioration of the heat exchanger's thermal performance due to the effect of the two-dimensional flow nonuniformity.

A fair estimate of the deterioration of the exchanger performance may be obtained using this factor as a tool. Due to the heat transfer process, which may result in viscosity variations, two-phase flows, or density variances, the flow homogeneity across an exchanger can be disrupted. A steady-state maldistribution or a transient or oscillating-type flow may arise from these self-induced maldistributions. When the viscosity of the fluid flows through the tubes, such as when cooling a viscous liquid, there is a risk of flow and, as a result, a significant loss in thermal performance in any exchanger working in laminar flow.

This happens because to the viscosity's significant effect on the pressure decrease. If the flow in one tube slows and therefore the viscosity rises, the average temperature of the tubes in parallel at the same terminal pressures decreases, causing a slower flow. Meanwhile, the flow in the other tubes rises for the same total flow, resulting in less cooling and therefore a lower viscosity, which tends to induce a flow increase. This issue has been referred to as a "frozen" problem. The pressure drop versus flow curves in a five-tube exchanger for cooling an oil. At b, all tubes have the same flow. The rising flow curve is for an unlimited number of tubes, while the decreasing flow curve. The divide between the fast and slow flow tubes is determined by flows between a and b or m and II. The decrease in thermal performance that happens when this laminar maldistribution occurs may be significant.

Unfortunately, there is no single criterion for determining the probability of a maldistribution other than the pressure drop being greater than the maximum (point a); thus, it is necessary to investigate the effect of changed operating conditions (temperature) or changed tube dimensions on the pressure drop curve. It is not difficult to calculate the curve. Many of these maldistribution issues may be avoided using a multipass exchanger. There are many kinds of maldistributions and instability issues. One is the well-known "steam hammer" or slugging of condensate, and another is the cycling of exit condensate or wall temperatures, which is common in complete condensers. Tube failures have been caused by both kinds. In heat exchangers with either tube-side or shell-side condensation, another kind of maldistribution develops.

The following are the required criteria for this specific condensing heat flux maldistribution: parallel routes with no mixing (i.e., condensing within tubes or flows restricted by tube supports), the same total pressure drop, and a distinct heat flux or heat load for each parallel path If these circumstances exist, parts of the heat exchanger surface become thermally inactive; if no non condensable gases are present, either a buildup of non-condensable gases or condensate sub cooling occurs. The parallel pathways, the identical pressure drop per path, and the cause for the heat flux variance for each path are all commonalities of this heat flux maldistribution for both tube-side and shell-side condensation. With condensing systems, there are many kinds of maldistributions and instability issues. One is the well-known "steam hammer" or slugging of condensate, and another is the cycling of exit condensate or wall temperatures, which is common in complete condensers.

Tube failures have been caused by both kinds. If the vapors include non- condensable gases, the rate of condensation is slowed, and the "chugging" or "steam hammer" is eliminated. In heat exchangers with either tube-side or shell-side condensation, another kind of maldistribution develops. Parallel routes with no mixing (i.e., condensing within tubes or flows restricted by tube supports), the identical total pressure drop for each parallel channel, and a distinct heat flux or heat load for each parallel path are all required for this condensing heat flux maldistribution. If these circumstances exist, parts of the heat exchanger surface become thermally inactive; if no non-condensable gases are present, either a buildup of non-condensable gases or condensate sub cooling occurs. Mechanical and tube vibration issues may also be caused by misdistributions.

Maldistributions on both the tube and shell sides may be dangerous when combined. For the peripheral tubes, a large exchanger with an axial nozzle for the tube-side fluid may provide a small flow decrease. Despite the fact that the E stream leakage, as estimated by a stream analysis software, seemed to be a fair proportion of the overall shell-side flow, it was a significant flow when compared to the flow in the peripheral tubes. As a result of the C and E streams, the peripheral tubes had a low flow within the tubes and a large flow outside the tubes. The total maldistribution for the periphery tubes in one big exchanger with a notional average heat capacity flow ratio of R = 1 was R = 1/3, whereas R was nearly 1 for the center tubes. The center tubes collapsed due to stress fractures since they were at a greater temperature than the periphery tubes. While a single stream's maldistribution is insignificant, the combined maldistribution of both streams in this instance may result in a substantial reduction in thermal performance and a severe mechanical issue.

Systems using radiant, electrical, or nuclear energy sources are particularly vulnerable to harm from misdistribution. Because the rate of heat transfer is unaffected by the fluid's flow or temperature, the temperature of the fluid and/or tube walls may easily surpass acceptable limits. Special care is required to ensure a proper flow distribution in these systems. Maldistribution may also cause tube or orifice erosion, as well as tube vibration, which can lead to tube collapse.

3. CONCLUSION

The impact of flow maldistribution on the average effective temperature differential is the most significant factor influencing heat transfer performance. The coefficient variation is a small issue. At nominal NTU, most flow maldistributions result in a small performance decrease, while at high NTU (> 10) they result in a significant performance loss. The typical safety factor and fouling tolerances offer enough additional surface for the exchanger-delivered performance to match the design load, thus the impact of a maldistribution goes undetected. Large temperature disparities and thermal stress failures may occur from certain combinations of maldistributions on both sides. Oscillating flows cause temperature fluctuations, which may lead to metal fatigue. Surge liquid flows may also harm equipment and cause operational control issues. Despite significant progress in the instability theories that explain oscillations, there are still some unexplained departures from theory. The original sources must be examined due to the theories' complexity and limitations. A few current or important references are provided to help the reader get a better grasp of these occurrences.

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