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ROTATION VANES UPSTREAM OF PIPE ELBOWS IMPROVES FLOW METER ACCURACY AND DECREASES REQUIRED STRAIGHT PIPE METER RUN LENGTHS

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ABSTRACT

The accuracy of many flow measurement devices depends upon a well developed uniform flow to the measuring device. Pipe elbows can create flow disturbances which inhibit accurate measurement. This paper describes the flow in ordinary pipe elbows and the flow through pipe elbows using a CRV rotation vane installed ahead of the elbow to eliminate the flow disturbances. Data is presented from laboratory testing, field results, and computer simulations which provide verification of the effectiveness of eliminating elbow induced flow disturbance.

FLUID SEPARATION IN PIPE ELBOWS CREATES FLOW PROBLEMS

Flow metering devices cannot provide accurate measurement of the flow rate through a pipe when flow entering the measurement device is distorted. Consequently, flow meter manufacturers and a number of independent organizations, such as ASME, recommend that flow meters not be installed near, and downstream of elbows.

Figure 1A (left) illustrates the flow through a plain pipe elbow. As a result of the forces acting on the fluid as it passes through the elbow, two flow separation regions result. Because of the existence of these regions, the remaining cross-sectional area through which the fluid must pass is significantly reduced (Figure 1B - left) and the local velocity is increased and directed toward the outer wall of the elbow. This is the reason for severe erosion on the outer wall for two-phase fluids with particulate matter. The boundary, between the large inner separation region and the high speed core flow, causes shed vortices that are the source of the large scale turbulence.

Measured cross-stream velocity profiles from the inner wall at the bottom to the outer wall at the top were measured. The measurements were made of the flow velocity distribution using a pitot-static rake inserted at the measurement stations. The resultant cross stream velocity profiles are shown in Figure 1C left. the velocity profiles were measured every 1/4 diameter for a diameter and half downstream of the exit for the plain elbow. The lines numbered 1-1 to 6-6 are the successive downstream measuring locations (1-1 & 2-2). Evidence of the inner wall separation (reverse flow at the inner wall) persists through the first two measuring stations. At 1-1/2 diameters downstream of the exit (station 6-6) there remains a strong cross stream velocity gradient. A downstream distance of several diameters is required for this gradient. A downstream distance of several diameters is required for this gradient to die out. This data indicates non-uniform velocity profile as the fluid exits the elbow.

Figure 2A shows a computer simulation of a short radius elbow using computational flow dynamics. The program simulates a 5'-0" I.D. elbow with air flowing at 3 ft/sec. The fluid enters the elbow with no angular momentum. This simulation shows high velocity flow at the inner wall of the elbow and low velocity and backmixing immediately after the elbow. The predicted flow dynamics agrees with the measured data shown in Figure 1C (left).

IMPROVING FLUID FLOW WITH VANES

A CRV flow conditioner, shown in Figure 3, is a set of stationary vanes installed upstream of a piping elbow, which introduces a rotational vector into the entering fluid flow. Figure 4 highlights the aerodynamic design of the CRV rotation vanes. The blades are designed with a zero angle of attack and a contoured aerodynamic shape to create a solid body rotation.

The CRV rotation vane allows the fluid to negotiate the turn in an elbow with all stream elements travelling the same distance from the entrance to the exit as illustrated in Figure 1A (right). The classic kidney shaped cross sectional flow pattern thus is not

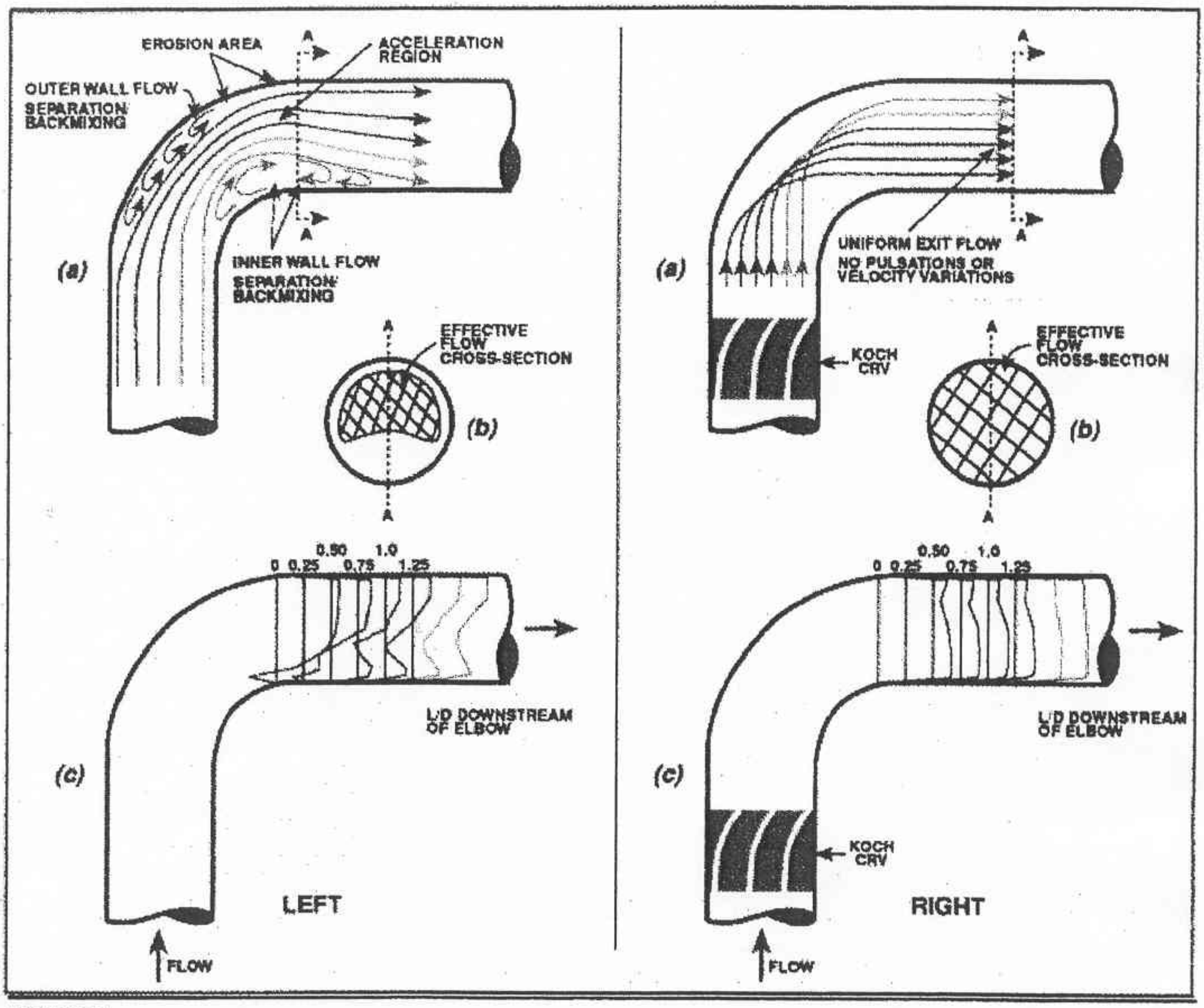

FIGURE 1

developed, nor are the flow separation regions.

Cross flow velocity profiles were measured downstream from an elbow exit with a CRV rotation vane prior to the elbow. These profiles are shown in Figure 1C (right). It is seen that the flow separation that existed at the inner wall for the plain elbow case has disappeared, and that by one and half diameters downstream the velocity profile is uniform.

Figure 2B which shows a simulation with the same conditions as Figure 2A except the fluid entering the elbow is given an angular velocity component to simulate spinning the fluid. The simulation predicts high velocity at the inner wall, but does not predict the backmixing and non-uniform velocity that occurs at the exit of a plain elbow. Spinning the fluid entering the elbow eliminates disturbances caused by the elbow and creates a uniform velocity profile at the elbow exit.

The simulation also agrees with the measured data shown in Figure 1C (right) which is shows that by giving the fluid the proper angular velocity component as it enters an elbow, the fluid will pass the elbow in a relatively undisturbed manner and exit with a uniform velocity profile.

FLOW METER ACCURACY

As stated earlier, flow metering devices cannot provide accurate metering of the flow rate through a pipe when the flow entering the metering device is distorted as is the flow downstream of an elbow. In recognition of the fact that a distorted flow distribution will recover into an axially symmetric distribution after travelling for some distance through a straight pipe, flow meter manufacturers often recommend installation of the

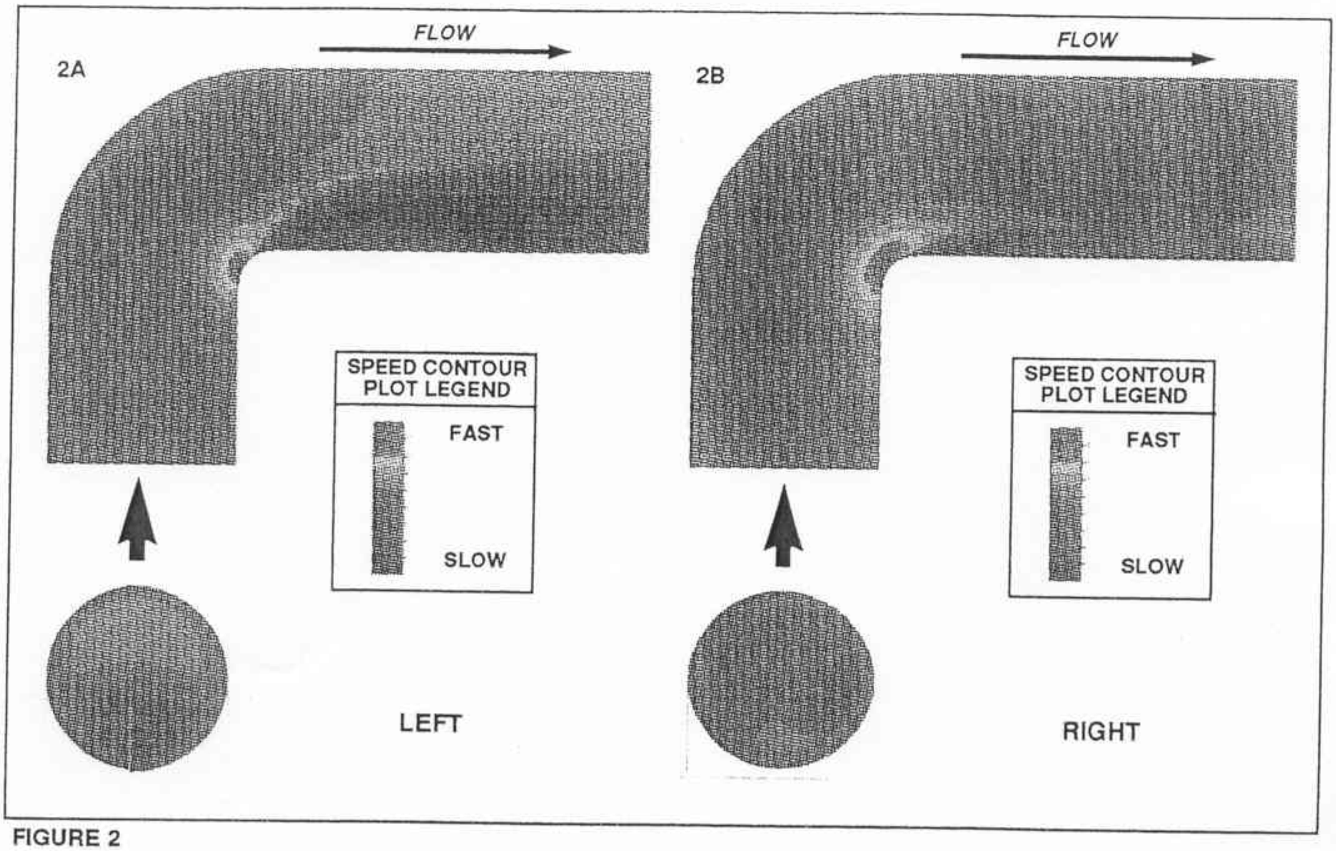

FIGURE 2

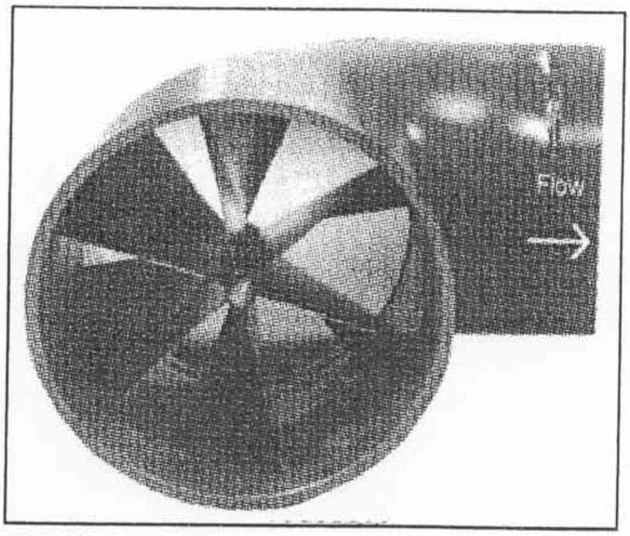

FIGURE 3

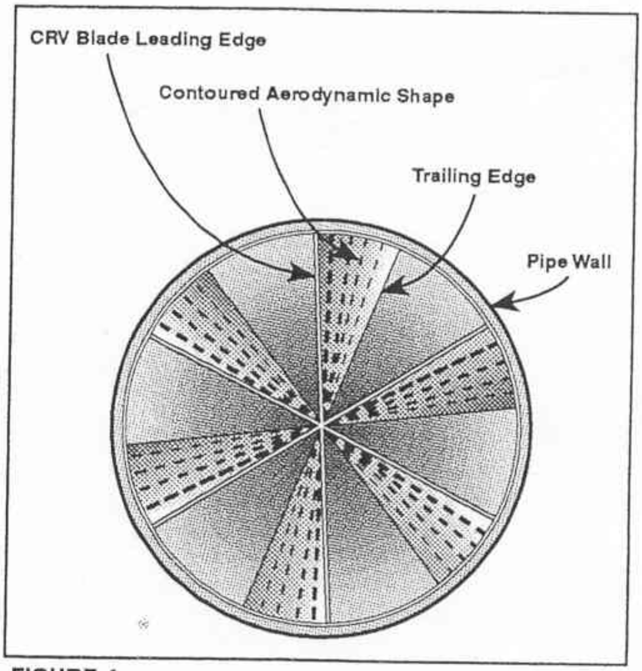

FIGURE 4

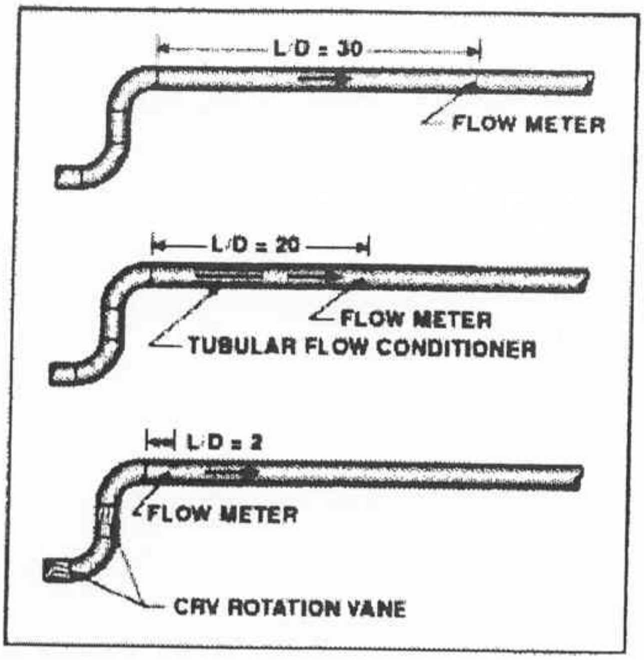

FIGURE 5

meter 30 diameters downstream of an elbow (Figure 5A).

Since straight pipe meter runs of up to 30 diameters are usually difficult to achieve due to lack of space and/or prohibitive costs, the installation of classic straightening vanes in the straight pipe ahead of the flow meter can reduce the required straight pipe run as shown in Figure 5B.

Many straightening vane designs are well suited to create even fluid flow profiles, however all straightening vanes have three distinct disadvantages. (1) Straightening vanes are installed after an elbow to solve a problem that has been created by the elbow. (2) Straightening vanes consume a pressure drop in order to straighten flow. (3) Straightening vanes often require 3 to 5 diameters of straight pipe before the vanes and sometimes as many as 15 diameters after the vanes due to turbulence from the trailing edge of the vanes.

Figure 5C shows that installation of a CRV rotation vane ahead of a pipe elbow will eliminate long meter runs and/or the need for straightening vanes. Because the uniform velocity profile is created immediately at the elbow exit with the CRV rotation vane, long meter runs are not required to obtain good flow measurements. The required meter run for such an installation is reduced to less than 5 diameters.

Using a CRV rotation vane in designing a new meter run application will allow for a shorter pipe run lengths. This saves money on initial capital costs and also reduces the area required for installation. Using a CRV rotation vane in an existing application allows for accurate flow measurement, when none was previously allowed.

EXAMPLES

CHEMICAL PLANT AIR FLOW MEASUREMENT

A southwest chemical plant had a flow meter located in an 18" header. Two separate 10" pipes were attached to the header. Flow meters were mounted in each of the 10" pipes about 6 diameters downstream of the elbows. The fluid was air and the meters were hot wire anemometers. Comparing the flow rate as measured by the upstream meter with the sum of the readings of the two downstream meters resulted in an indicated difference of about 30% in total flow. CRV rotation vanes were installed between the downstream meters and the elbows. The subsequent comparisons of total flow were within 5% of each other.

REFINERY AIR FLOW MEASUREMENT

Several 18" diameter CRV units are installed in a refinery ahead of the flow metering instruments. This type of installation resulted in the saving of 25 diameters of straight pipe run, or 38 feet of 18" pipe. In plants where only a short meter run was provided, installation of CRV rotation vanes will result in more accurate measurements.

SUMMARY

Process plants are under constant pressure to decrease operating costs and to increase capacity, efficiency, and reliability. Fluid flow problems through elbows, which are often difficult to recognize and detect, limit the engineer's ability to meet these plant goals by adversely affecting the performance of key equipment within a process plant.

The Crv flow conditioner has successfully eliminated flow separation and turbulence in piping elbows. This creates accurate flow meter measurement and allows for increased process operating efficiency. The case histories discussed have given practical examples in which the application of the rotation vanes have resolved piping system operational problems resulting from elbow separation.

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If you have any further questions, please contact Mr. Lee A. Kosla at Cheng Fluid Systems, Inc.