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FLOW METERING MODIFICATION FOR AVOIDING CONTROL VALVE CAVITATION IN HYDROCARBON INDUSTRY

Pongsak Pilaoon, Sart Kummool, Prasit Julsereewong and Amphawan Julsereewong

Faculty of Engineering
King Mongkut's Institute of Technology Ladkrabang
Ladkrabang, Bangkok 10520, Thailand
ppilaoon@gmail.com; { sart.ku; prasit.ju; amphawan.ju }@kmitl.ac.th

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Abstract. *This paper presents a practical technique for solving noise and vibration problems caused by control value cavitation in existing pipeline measurement system for condensate residue flow metering of an aromatics plant in hydrocarbon industry. A cause of cavitation in the control valve is due to change in the purpose of flow metering system from use for custody transfer measurement to use for normal process monitoring and control. In order to avoid damaging effects of cavitation, pipeline modification by installing a new monitoring and control system is proposed. Based on the recommended practice of International Society of Automation (ISA) for evaluating control valve cavitation, the evaluation results confirm that no incipient cavitation occurs in the selected control valve for new installation in the proposed modification under normal service conditions.*
Keywords: Control valve, Cavitation, Noise, Vibration, Evaluation, Pipeline modification, Hydrocarbon industry

1. **Introduction.** The most common final control element in process control applications in petrochemical and hydrocarbon industries is the control valve for adjusting the flow of fluid such as water, gas, steam, and chemical compounds in a process [1]. Selecting a properly sized control valve is essential to attain the highest degree of process control for the fluid, because the control valve exerts a direct influence on the process. Sizing a control valve incorrectly is a technical and economical mistake. An undersized control valve will not pass the required flow, while an oversized control valve (most often the case) will be unnecessarily expensive and have poor controllability to exactly adjust the required flow. Usually, control valves are sized to control between 20-80% opening of the valve. The nature and condition of the fluid in a given application are thus required to be considered in control valve selection during design phase [2]. This implies that a large difference between actual and design process conditions has a high impact on the performance of control valve installed in existing plant. Especially, during low liquid-flow demand, the large-sized control valve operates in nearly closed position, potentially resulting in cavitation. The valve cavitation in pipeline measurement system is a concern for plant maintenance personnel because of the high maintenance cost and unplanned downtime. The cavitation not only decreases flow capability through the control valve, but it may also cause excessive noise, excessive vibration, and material damage [3,4]. The extent of cavitation damage is a function of several factors such as fluid, quantity of flow, magnitude of pressure drop, time of exposure, materials of construction, and design of control valve trim. There are two methods for minimizing unacceptable levels of control valve noise and vibration in existing system: pipeline modification and valve internal constitution reform [5]. The latter varies from manufacturer to manufacturer of the control valve used.

The aim of this paper is to present a pipeline modification to avoid control valve cavitation, which occurred in the existing flow metering system in an aromatics plant of an integrated petrochemical and refining company in Thailand. This paper is organized in five sections including this introduction. The next section describes the flow metering for custody transfer, which was used before modification. Section 3 and Section 4 provide the proposed modification and the standard evaluation results, respectively. The last section gives the conclusions.

2. **Flow Metering for Custody Transfer.** Figure 1 shows a schematic diagram of the interested pipeline measurement system in the aromatics plant. Natural-gas condensate is a low-density mixture of hydrocarbon liquids that may contain liquid petroleum gas (LPG) and is typically high in both light naphtha and heavy naphtha. The feed fractionation unit is utilized to process the incoming full-ranged condensate from natural gas well and the full-ranged naphtha from crude oil distillation unit into the heavy naphtha and by-products such as LPG and condensate residue. In the past, the interested metering skid was used for custody transfer flow measurement to pass the condensate residue from the feed fractionation unit in the aromatics plant to a customer. Payment involving contractual agreements between buyer and seller was made as a function of the amount of condensate residue transferred. The flow metering skid as illustrated in Figure 2 is a frame device on which various assemblies such as flow transmitter, temperature transmitter, pressure transmitter, and control valve are installed.

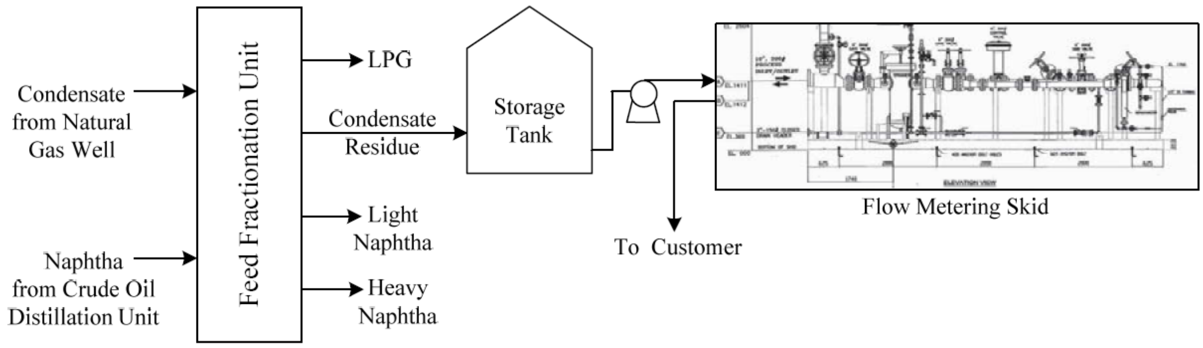

FIGURE 1. Schematic diagram of the pipeline measurement system for custody transfer

FIGURE 2. Flow metering skid for condensate residue custody transfer

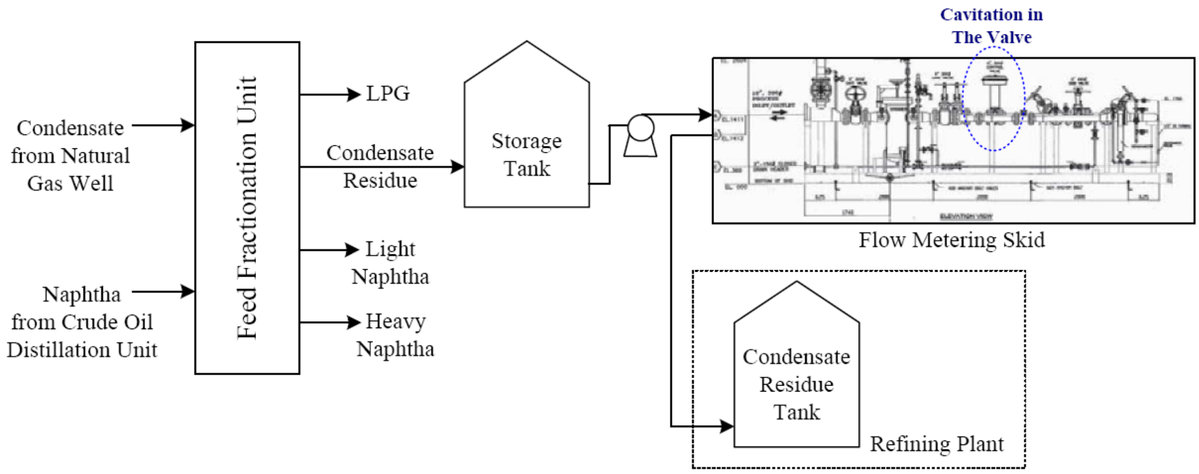

Figure 3. Schematic diagram of the pipeline measurement system for process control

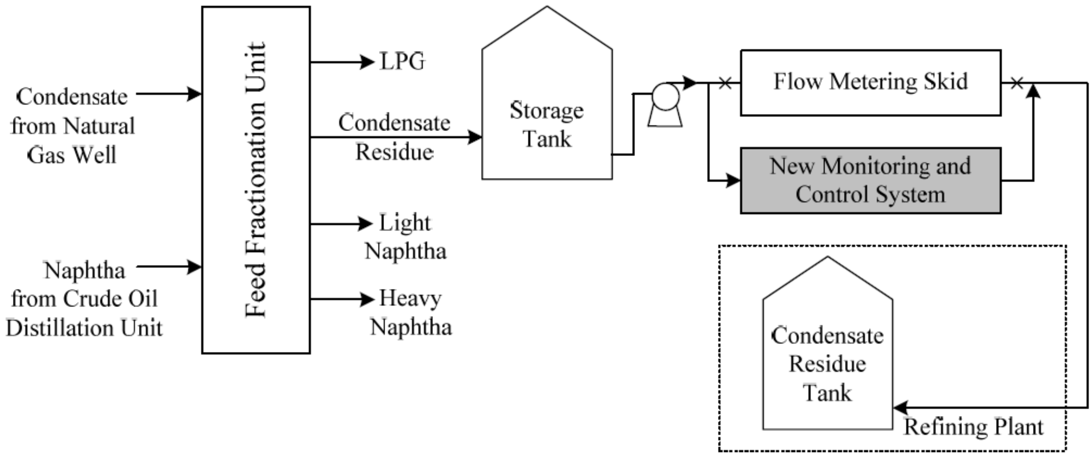

Figure 4. Proposed modification by installing a new monitoring and control system

The studied aromatics plant was recently merged with a refining plant owned by the same parent company for integrated operation through the exchange of raw materials. As a result of the merger, the custody transfer of condensate residue from the feed fractionation unit is cancelled. The condensate residue is transferred to use in the refining plant as shown in Figure 3, and thus the purpose of flow metering skid is changed from use for custody transfer flow measurement to use for process monitoring and control. Unfortunately, changing the use of flow metering skid has a negative impact on the control valve operation. In new application, the required flow rate for transferring condensate residue to the refining plant is largely reduced, and thus the control valve operates in nearly closed position to handle the desired process condition. This causes the control valve installed in the flow metering skid to be very sensitive to operating conditions. Unacceptable noise and vibration problems due to the fact that control valve cavitation occurred. The cavitation is a two-stage phenomenon. The first stage involves the formation of vapor bubbles, and the second stage is the collapse or implosion of the vapor bubbles.

3. **Proposed Modification.** Figure 4 shows the proposed modification by building a pipeline for installing a new monitoring and control system as depicted in Figure 5 to bypass the existing flow metering skid, which is preserved for future use.

Table 1 gives an instrument list and specific service conditions for implementing the new monitoring and control system. Three field devices are based on Foundation Fieldbus

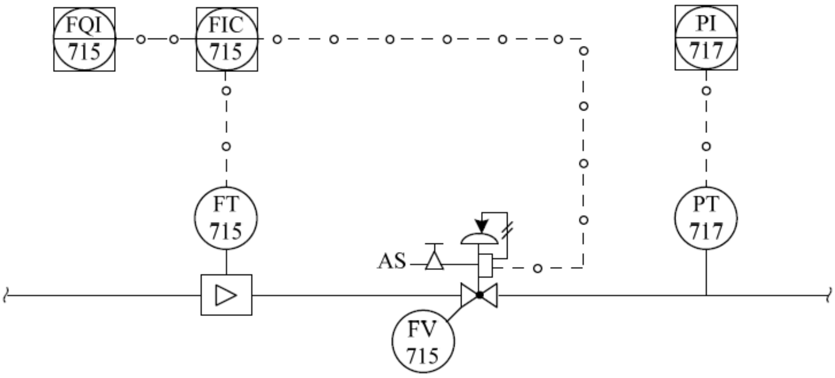

FIGURE 5. Schematic diagram of the new monitoring and control system

TABLE 1. Instrument list for new monitoring and control system

Tag	Service	Instrument Type	Communication Technology	Location	Range	Unit
FT-715	Condensate Residue	Vortex Flowmeter	Foundation Fieldbus	Field	0-300	m^3/h
FIC-715	Condensate Residue	Flow Indicator and Control	System Internal	DCS	0-300	m^3/h
FQI-715	Condensate Residue	Flow Accumulation	System Internal	DCS	–	ton
FV-715	Condensate Residue	Globe-Style Control Valve	Foundation Fieldbus	Field	0-100	%
PT-717	Output Pressure	Pressure Transmitter	Foundation Fieldbus	Field	0-25	barg
PI-717	Output Pressure	Pressure Indicator	System Internal	DCS	0-25	barg

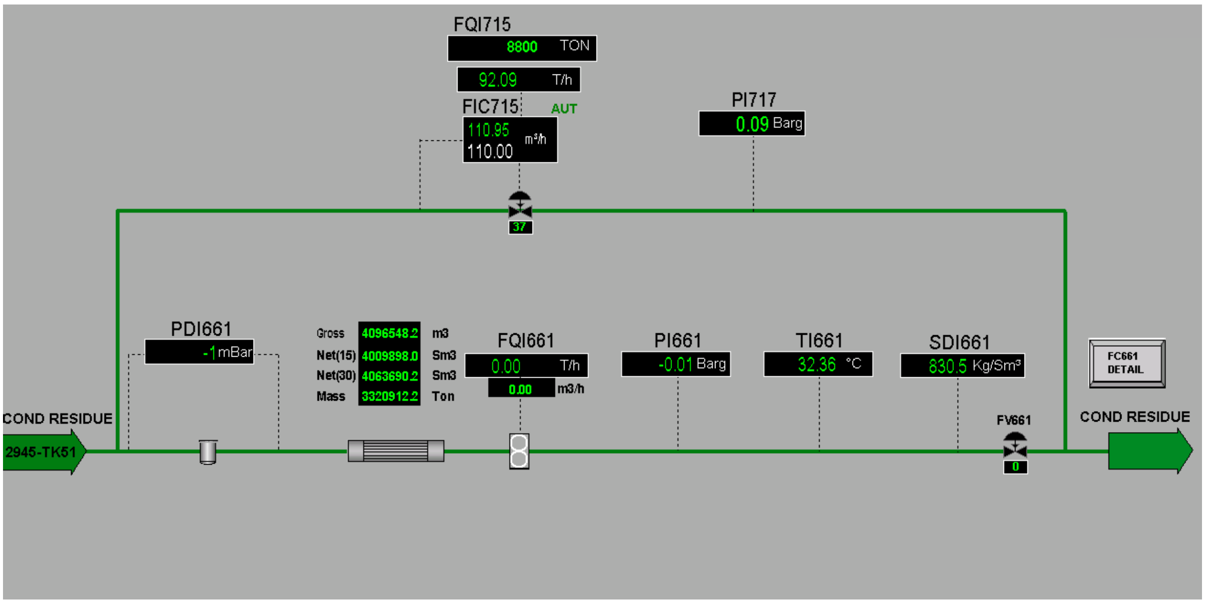

FIGURE 6. Graphic user interface on the operator workstation in the central control room

technology. The vortex flowmeter (FT-715), DCS controller (FIC-715), and control valve (FV-715) are utilized to control the flow rate of condensate residue. The purpose of this feedback control loop is to maintain the flow rate at the desired setpoint. In addition, the flow accumulation of condensate residue transferred to the refining plant is also monitored in real-time. The pipeline output pressure is measured by the pressure transmitter (PT-717), and this measured value is sent to be monitored at the central control room (see Figure 6).

4. **Evaluating Cavitation of the Selected Control Valve [6,7].** Process conditions that the control valve will encounter in service are summarized in Table 2 for selecting the type and size of control valve (FV-715) used in the proposed modification. To determine the valve sizing coefficient, C_v, for the valve used to control the flow of liquid, the liquid valve sizing equation (metric unit) can be given by

$$C_v = 1.17q\sqrt{G_f/\Delta P} \tag{1}$$

where q is the flow rate (m^3/h), G_f is the specific gravity of the liquid at operating temperature, and ΔP is the pressure drop across the valve, or inlet minus outlet pressure (bar). Substituting the process data from Table 2 into (1), the C_v values for the minimum flow rate, normal flow rate, and maximum flow rate are equal to 6.52, 33.3, and 90.7, respectively. From these results of valve sizing calculations, major details of the selected control valve are as follows.

Manufacturer: Masoneilan, **Model**: 88-41335, **Size**: 6 inch,
Type: ANSI Class 300 globe valve, **Design**: Anti-Cavitation, Single State
Flow Characteristic: Equal Percentage, $\mathbf{C_v}$ **Range**: 3.9-155

In order to evaluate the control valve cavitation, a cavitation index at service conditions, σ (service), can be stated as

$$\sigma(\text{service}) = \frac{P_1 - P_v}{P_1 - P_2} \tag{2}$$

where P_1 is the valve inlet static pressure, P_v is the absolute fluid vapor pressure of the liquid at the inlet temperature, and P_2 is the valve outlet static pressure.

Table 2. Process conditions from hydraulic calculation used for sizing control valve

Fluid	Fluid State	Condensate Residue		Liquid	
Flow Rate @ Min./Normal/Max.		21.00	92.77	155.0	m^3/h
Inlet Pressure/Valve Drop @ Min. Flow		14.63	barg	11.79	bar
Inlet Pressure/Valve Drop @ Normal Flow		14.07	barg	8.82	bar
Inlet Pressure/Valve Drop @ Max. Flow		12.56	barg	3.3	bar
Design Temperature	Operating Temp	63	°C	38	°C
Design Pressure	Mol. Weight	29.5	barg	–	
Viscosity	Upstream Density	2.04	cst	830	kg/m^3
Vapor Press @ Op Temp	True Critical Press	0.002	bara	21	bara
Specific Gravity @ Op Temp		0.83			

There are five cavitation levels for determining the degree to which cavitation is occurring, i.e., incipient, constant, incipient damage, choking, and maximum vibration. The cavitation at point of 'incipient cavitation' is not damaging, whereas the cavitation at point of 'maximum vibration cavitation' can subject valve and piping to severe damage. The 'incipient caviation' level is utilized for evaluating the valve selected to use in the proposed modification. The point of 'incipient cavitation' at which the first bubbles are formed can be predicted by using the coefficient of incipient cavitation, σ_i, which can be written as

$$\sigma_i = 1/K_C \tag{3}$$

where K_C is the incipient cavitation factor specified by the valve manufacturer.

From technical datasheet of the control valve selected, the factor K_C is equal to 0.83, and thus the coefficient σ_i is equal to 1.2 at the point where incipient cavitation begins to occur. Comparing between two coefficient values, σ (service) and σ_i, if the σ (service) is greater than σ_i, then it can be approximately evaluated that no incipient cavitation occurs in the selected valve at service conditions.

Practically, the cavitation behavior and cavitation coefficients are not constant with either different upstream pressure or valve size. The change in the value of a cavitation coefficient associated with change in pressure is defined as the pressure scale effect (*PSE*), which can be stated as

$$PSE = [(P_1 - P_v)/(P_1 - P_v)_R]^a \tag{4}$$

where the subscript R refers to reference pressure, and the exponent a is related to the selected valve type. The change in the value of a cavitation coefficient associated with valve size (d) is defined as the size scale effect (*SSE*), which can be given by

$$SSE = (d/d_R)^b \tag{5}$$

$$b = 0.068\left(C_v/N_1 d^2\right)^{1/4} \tag{6}$$

where d_R and N_1 refer to the reference value and the numerical value of the cavitation coefficient, respectively. The cavitation coefficient of the selected control valve, σ_v, can be expressed by

$$\sigma_v = (\sigma_R SSE - 1)\, PSE + 1 \tag{7}$$

where σ_R is a reference coefficient, which can be chosen as the value of the coefficient of incipient cavitation σ_i. The calculated σ_v can be compared to σ (service) for evaluating the cavition in the control valve. If σ (service) is greater than σ_v, then the selected valve will operate at a level of cavitation less severe than that for which the valve reference coefficient σ_R was determined by the manufacturer.

Using (2)-(7), process conditions in Table 2, and the technical datasheet of the selected control valve, the calculation and comparison results for evaluating the valve are summarized in Table 3. From comparison results between σ (service) and σ_i, it is seen that σ (service) is greater than σ_i for all three flow rate conditions, and thus it can be approximately evaluated that incipient cavitation cannot occur in the selected valve at specific service conditions. From comparison results between σ (service) and σ_v, it is shown that σ (service) is less than σ_v for minimum flow rate condition only; therefore, it can be evaluated definitely that incipient cavitation can occur when the pressure drop across the

Table 3. Calculation and comparison results for evaluating the selected control valve

Flow Rate (m^3/h)	C_v	% Opening	Predicted SPL (dBA)	σ_i (σ_R)	σ (service)	σ_v	Comparison Results
21.00 (Min.)	6.52	20	78	1.2	1.25	1.258	σ (service) $> \sigma_i$ σ (service) $< \sigma_v$
92.77 (Normal)	33.3	45	75	1.2	1.61	1.28	σ (service) $> \sigma_i$ σ (service) $> \sigma_v$
155.0 (Max.)	90.7	76	60	1.2	3.85	1.29	σ (service) $> \sigma_i$ σ (service) $> \sigma_v$

valve is relatively high in the case of extremely low flow rates. However, incipient cavitation usually does not cause damage. Additionally, no objectionable noise, vibration, or damage to valve equipment occurs at normal and maximum flow rate conditions.

5. **Conclusions.** A useful technique for modification of existing flow metering system in hydrocarbon plant has been proposed in this paper. The proposed modification has been required to avoid the damaging effects of control valve cavitation in the replaced flow metering skid. In addition, how to use cavitation coefficients to evaluate the selected control valve for installation in the new monitoring and control system in specific service conditions has been also described. Selecting and sizing the right control valve to prevent the damaging cavitation has been verified by evaluation results. In future work, cavitation phenomena in the proposed modification system will be experimentally investigated.

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