

HYDRAULICS**JGS 210-120-1-37E**

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1. SCOPE

- (1) This standard practice provides the guidelines for the sizing of piping system in refineries, petrochemical plants and similar plants.
Gas or liquid pipelines are outside the scope of this standard practice.
- (2) Specific instructions given in the Project Specifications have precedence over the requirements given in this standard practice.
- (3) No alternation from the Project Specifications and this standard practice are permitted unless otherwise specified.

2. WORK PROCEDURE**2.1 Input to the Design****2.1.1 Process Conditions**

The data to be used for the hydraulic design, such as the flow rate, temperature, pressure and so on should be clarified on the following:

- (1) Source of the data

The design data will be obtained from, but not limited to, the following documents;

- Process Flow Diagram (PFD)
- Basic Engineering Design Data (BEDD)
- Piping & Instrument Diagram (P&ID)
- Plot plan
- Equipment data sheet
- Piping material specification

- (2) Operation case to be taken as the design base
- (3) Related documents to be used as a part of the input data
- (4) Related documents to be checked or revised based on the results of hydraulic design

The data to be used for the hydraulic design should be distinguished into changeable data and unchangeable data as a consequence of the hydraulic design.

2.1.2 Input Data

The following is a summary of input data to be prepared before the hydraulic design.

- (1) Operational data

- Service for identification
- Fluid name for identification
- From-To for identification
- Flow rate(s) of liquid and/or vapor
- Temperature
- Pressure
- Physical properties

Liquid service : Density, Viscosity, Vapor pressure, Critical pressure, SpGr @15°C

Vapor service : Density, Viscosity, Molecular weight, Cp/Cv, Z-factor

Two-phase flow : Densities and Viscosity for both liquid and vapor and Surface tension

- (2) Construction data

- Line class
- Elevation at inlet and outlet of piping system
- Distance between source and destination, sum of XYZ coordinate length.
- Instruments, types and quantities
- Valves & fittings, types and quantities, if available.
- Control valve(s)
- Pump(s), compressor(s) and blower(s)

(3) Design requirement

- Marginal head of the pump NPSH available, if any
- Over design % - specification of the design flow rate, if any
- Turndown % - specification of the minimum flow rate, if any

2.2 Output from the Design

The hydraulic design should ensure the system performance at desired condition with the following output data.

(1) Final line size

- Final line size(s) determined shall satisfy the design requirements.
- Equipment nozzle size(s) should be consistent with the final line size.

(2) Pressure balance

- Pressure balance calculation sheet including operating, design and pump shut-off pressure
- Pump specifications, referring to the pump data sheet for details.
- Instrument specifications, referring to the instrument data sheet for details.

(3) Equipment elevation

- Skirt height of towers, if the height is changed.
- Installation height of vessels and heat exchangers
- Installation height of instruments, if required.

2.3 Work Steps

The hydraulic design should be conducted according to the following work steps, as a guideline.

- (1) Prepare input data as listed in section 2.1.
- (2) Pipe inside diameter as shown in section 3.2.
- (3) Line sizing as shown in section 3.3.
- (4) Evaluate equivalent length as shown in section 3.4.
- (5) Evaluate pressure drop of piping components as shown in section 3.5.
- (6) Check pump suction line, when pump is provided, as shown in section 3.6.
- (7) Determine pressure drop of control valve as shown in section 3.7.
- (8) Prepare the hydraulic balance as shown in section 3.8.
- (9) Check the results as stated in 3.8.2 and 3.8.3.

3. HYDRAULIC DESIGN

3.1 General

3.1.1 Basic Principle for Line Sizing

- (1) The basic principle to determine the line sizes shall be based on economical aspects, i.e., minimizing the sum of operational costs and investment costs as described in paragraph 3.3.1 and Appendix-3.
- (2) However, line sizes should not exceed the limitations given in paragraph 3.3.2 to 3.3.8.
- (3) In some instances, the process requirements will take precedence over the economical aspects; for example, in the case of pump suction lines where the NPSH is the main concern.
- (4) The guidelines for practical line sizing given in paragraph 3.3.9 are determined in consideration of all aspects and are applicable in most cases without extra studies.
- (5) In revamping or modification projects of existing plant, fluid velocity is more likely to be increased than in new installation projects.

3.1.2 Pressure Drop Calculation Method

- (1) Frictional pressure drop shall be calculated using Moody's friction factor described in Appendix-1 A1.2 except fluid in (2), (3) and (4).
The following are typical fluids in this category.
 - General hydrocarbon
 - Chemically treated water such as cooling water, boiler feed water, etc.
- (2) Hazen and Williams empirical formula (Appendix-1 A1.3) shall be applied, taking the Hazen and Williams friction factor $C = 100$, for the following service ;
 - Sea water, flowing in untreated inner surface pipe
 - Oxygen contained and chemically untreated water such as drinking water, industrial water etc., flowing in untreated inner surface pipe
- (3) For compressible gas flow with high pressure drop, adiabatic flow formula should be applied as shown in Appendix-1 A1.4.
- (4) For gas/liquid two phase flow, HTFS method should be applied as shown in Appendix-2 A2.1 or HTFS Handbook TM4 (Aug., 1984).

3.2 Standard Pipe Data

- (1) When the line classification is available, the pipe data (outside diameter, wall thickness and so on) should be based on JGS 220-311-3-01E for JIS or JGS 220-311-3-03E for ANSI.
- (2) Unless otherwise specified, minimum line size should be $D_N \frac{3}{4}$ " except for instrument piping, auxiliary heating piping and connections to equipment.
- (3) Unless otherwise specified, $D_N 1\frac{1}{4}$ ", $2\frac{1}{2}$ ", $3\frac{1}{2}$ ", 5", 7", 9" and 22" should not be used. Final selection will be based on economical aspects.
- (4) When the line classification is not available, the pipe thickness may be assumed as follows.

Table-2 Typical wall thickness of pipe (assumed)

Flange rating	150 LB	300 LB	600 LB
Less than 2"	Sch. 80	Sch. 80	Sch. 160
2"	↓	↓	↓
3"	Sch. 40	Sch. 40	Sch. 80
4"	↓	↓	↓
6"	↓	↓	↓
8"	↓	↓	↓
10"	↓	↓	↓
12"	↓	↓	↓
14"	↓	↓	↓
16"	9.0 mm	9.0 mm	13.0 mm
18"	↓	↓	↓
20"	↓	↓	↓
24"	↓	↓	↓

Material : Carbon steel, Low alloy and Stainless steel.

If piping of over 24" is required, confirm the availability of such material and feasibility of application. For large size piping, nominal pipe size shall be at 4-inch intervals, but allowing the 30-inch diameter.

- (5) For stainless sanitary pipe, the pipe data should be based on the following standards:

ISO 2037	Metal Pipes and Fittings - Stainless Steel Tubes for the Food Industry
JIS G 3447	Stainless Steel Sanitary Tubing

3.3 Line Sizing

3.3.1 Economical Line Size

- (1) Optimum line size depends on economics, taking energy and investment cost into account. Fig. 1 to 6 should be applied for line sizing. The basis of the figures are as follows ;

- Onsite piping and turbulent flow, assuming negligible effect of fluid viscosity	
- Pump/compressor/motor efficiency	70%
- Electricity unit price	0.048 \$/kWh
- Annual operating time	8,000 h/y
- Capital return index	0.3
- Hot insulation	for 100 to 150 °C grade
- Cold insulation	for -15 to -30 °C grade
- Cost data	based on 1992 cost data and reviewed with 1994 data
- (2) Note that change of pump or compressor type and equipment design pressure are not considered in those figures. The figures cannot be applied to the gas flow with high pressure drop. Individual study may be required for critical cases. The calculation method to determine optimum line size is detailed in Appendix-3.
- (3) Pipe sizes selected by using Fig. 1 to 6 or Appendix-3 shall conform to the limitations given in paragraph 3.3.2 to 3.3.8. Line sizes shall not exceed those limitations.

Fig. 1 Carbon Steel

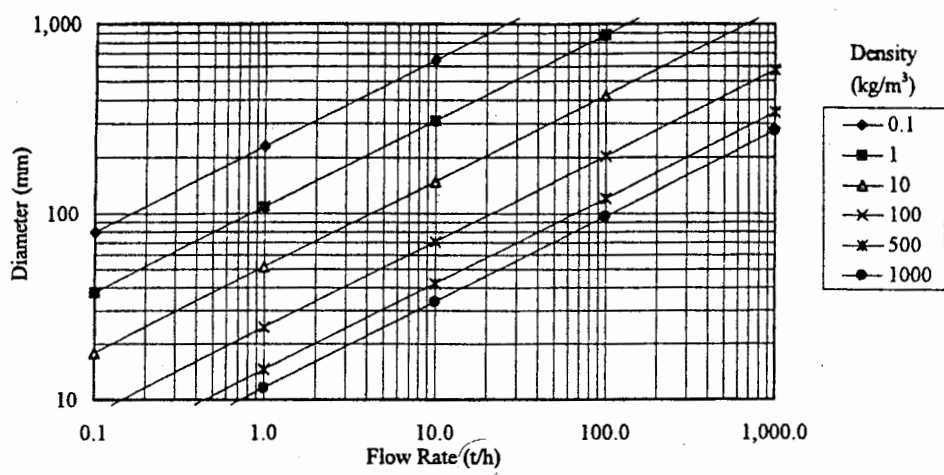
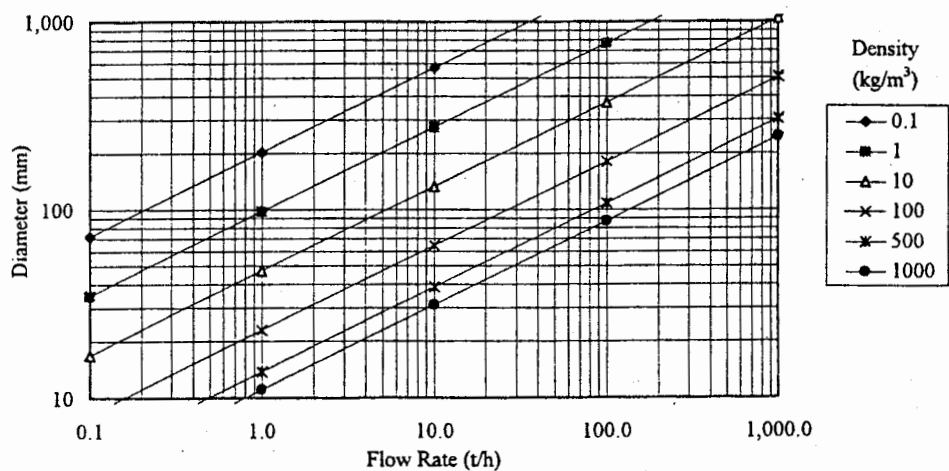


Fig. 2 Stainless Steel or 5Cr-½Mo



3.3.2 Limitations of Sizing

The lines should be sized within the limitations tabulated below. The detailed criteria will be given in the succeeding sections 3.3.3 to 3.3.8.

Table-3 Limitations of line sizing

	Erosional Velocity	Sonic Velocity	Noise Velocity	Minimum Velocity	Flow Pattern	Special Requirement
Liquid - general	Yes					Yes (Note-1)
Liquid - at boiling point	Yes					Yes (Note-2)
Gas or vapor		Yes	Yes			
Steam		Yes	Yes			
Gas / liquid two phase	Yes				Yes	
Steam condensate	Yes				Yes	
Slurry	Yes			Yes		Yes (Note-1)

(Note-1) Refer to 3.3.8(2) "Static electricity" and 3.3.8(3) "Connections to vessels".

(Note-2) Refer to 3.3.8(1) "Maximum pressure drop" and 3.3.8(3) "Connections to vessels".

3.3.3 Erosional Velocity

- (1) This criterion can be used where no specific information as to the erosive/corrosive properties is available. The velocity above which erosion may occur in gas/liquid two-phase flow can be determined using the following empirical equation. (API RP-14E 2.5a - 1991).

$$V_e = \frac{C_e}{\sqrt{\rho_m}} \quad \text{or} \quad \rho_m V_e^2 = C_e^2 \quad (1)$$

Where :

V_e = erosional velocity (m/s)
 ρ_m = homogeneous density (kg/m³)
 C_e = empirical constant given in Table-4 (m/s)(kg/m³)^{1/2}

This criterion shall be applied to carbon steel, low alloy and stainless steel piping.

Also, this criterion may be applied to liquid or gas services where erosion is not so severe as in two-phase services.

Table-4 Erosional velocity constant

C_e	Services
180 - 240	Solid-free fluids where corrosion is not anticipated or when corrosion is controlled by inhibition or by employing corrosion resistant alloys, continuous
300	Same as above but intermittent
120	Solids and/or corrosives are expected

(2) Water piping [14]

The maximum velocity should be less than the following.

Mortar or concrete	3.0 m/s
Mortar lining seal coat with paint	5.0 m/s
Steel cast iron or PVC	6.0 m/s

(3) Amine solution

The velocity in the Amine process should be less than the following;

Carbon steel	Liquid	3 m/s
	Vapor	30 m/s
Stainless steel	Liquid	9 m/s
	Vapor	36 m/s

(4) $\text{NH}_3\text{-H}_2\text{S-H}_2\text{O}$ solution [13]

In the effluent line of hydrocracking and hydrotreating processes, aqueous solutions of ammonium bisulfide often cause rapid erosion-corrosion of carbon steel pipes, especially nozzles, bends, tees, reducers and the air cooler tube inlet section downstream of water injection.

The maximum velocity shall be taken from Fig. 7 and 8.

Fig. 7 Performance of Steel-tubed Exchangers

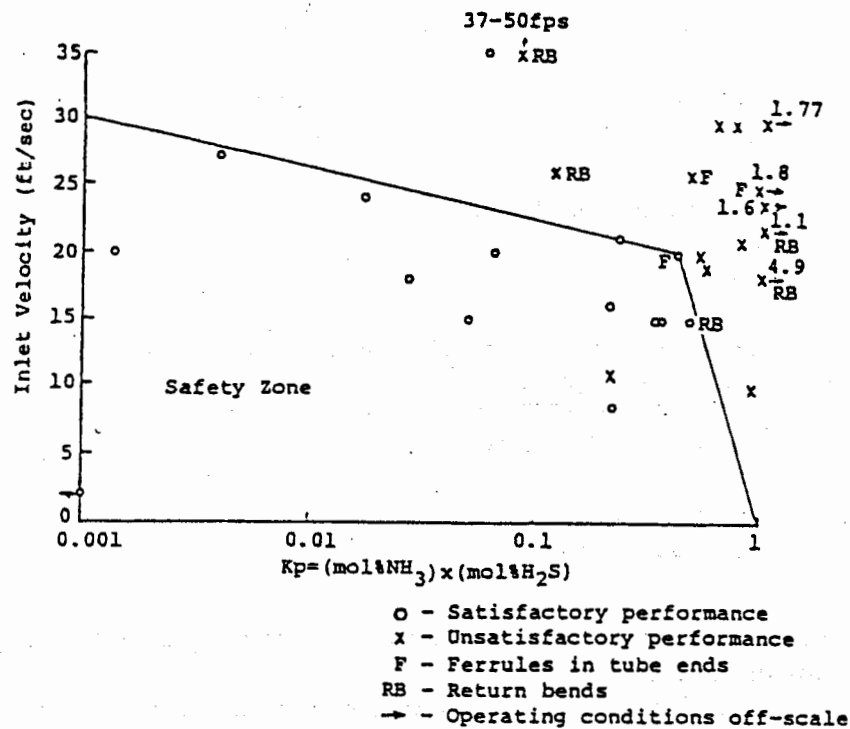
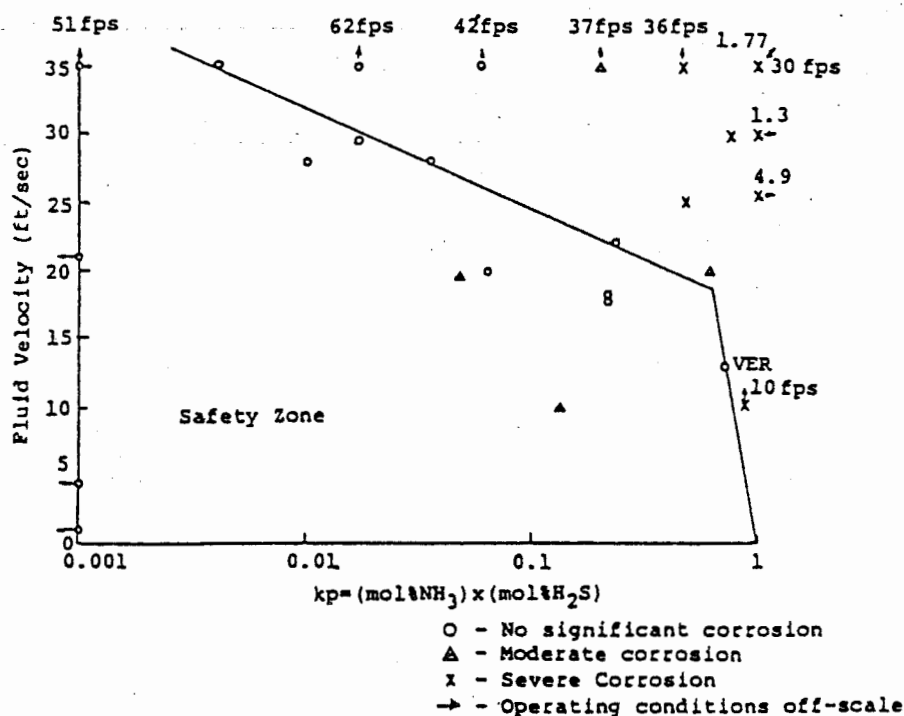


Fig. 8 Corrosion of Steel Piping



3.3.4 Sonic Velocity

- (1) The maximum velocity shall be less than 50% of the sonic velocity for continuous gas or vapor services.
- (2) For intermittent services, such as for pressure relief valve discharge piping, 80% (See Technical Report No. 2) of sonic velocity may be acceptable. Care should be taken over the back pressure limitations.
- (3) The sonic velocity can be calculated as follows.

$$V_{\text{sonic}} = \sqrt{\frac{g_c k R T}{M}} \quad (2)$$

Where :

V_{sonic} = sonic velocity	(m/s)
g_c = gravity conversion factor	(kg·m/kgf·s ²)
k = specific heat ratio = C_p/C_v	(-)
R = gas constant	(-)
$= 847.9 \text{ (kgf/m}^2\text{)(m}^3\text{)/(kg-mole)(}^\circ\text{K)}$	
T = temperature	($^\circ\text{K}$)
M = molecular weight	(-)

Sample Calculation 1 : Natural gas ($M = 18.0$, $k = 1.27$) at 60°C is flowing through a flare header at a velocity of 80 m/s. Calculate the percent of sonic velocity.

Solution : $V_{\text{sonic}} = [(9.81)(1.27)(847.9)(60 + 273) / (18.0)]^{0.5} = 442 \text{ m/s.}$

Hence, % of sonic = $(80) / (442) \times 100 = 18.1\%$.

- (4) When the valve's pressure drop is relatively high, e.g. steam injection, nitrogen header and so on, check the sonic velocity for valve downstream piping.

3.3.5 Noise

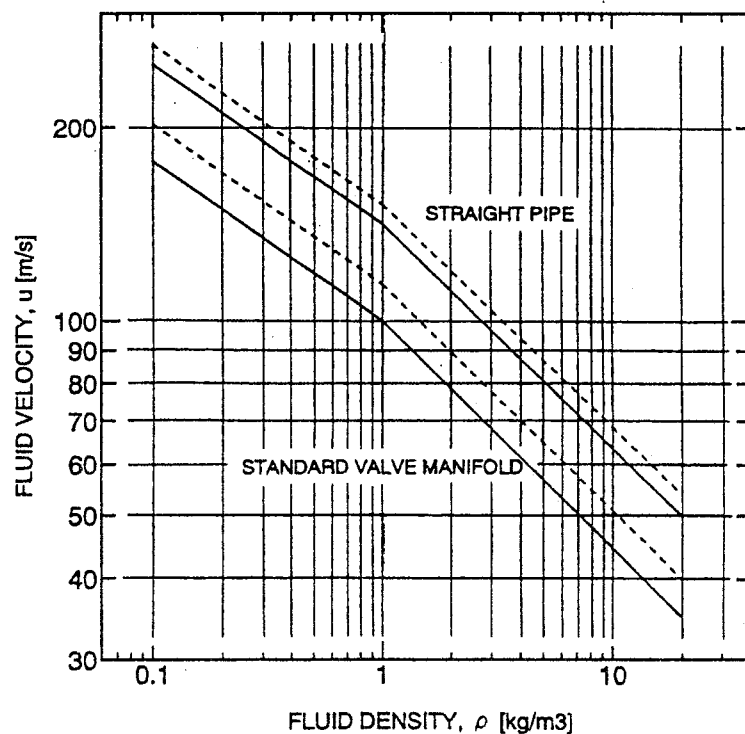
In order to eliminate excessive noise from piping, the maximum allowable fluid velocity shall be determined using the following chart, for gas and two-phase lines.

The chart is based on the permissible noise level of 85 dB(A) measured at one meter from pipe surface. This permissible noise level is most commonly used worldwide for pipe noise limitation. [20],[21],[22]

Fig. 9 Noise Limitation

Bare pipe : Solid line

Insulated pipe : Dotted line



3.3.6 Slurry Line**(1) Cycle oil**

The minimum and maximum velocities for cycle oil containing catalyst fines shall be as follows;

Minimum velocity 1.1 m/s

Maximum velocity 2.1 m/s

(2) Other services [23],[24]

If practical, flow velocity should not be less than 0.9 m/s to minimize the deposition of solids. [API RP-14E 2.3a - 1991]

The maximum velocity should be less than the erosional velocity, which will depend on the fluids and processes. This erosional velocity will, therefore, be provided by the process licensor.

3.3.7 Two-Phase Flow Pattern**(1) Appendix-2 shows the estimation method of pressure drop and flow pattern for gas/liquid two-phase flow.**

The method is based on the following:

Pressure drop : HTFS method

Flow pattern : TULSA university method

(2) Acceptable flow patterns

Annular flow is stable and preferable for both horizontal and vertical up flows.

For horizontal piping, stratified flow and bubble flow are stable.

For vertical piping, bubble flow is also stable.

CAUTION : AVOID SLUG FLOW FOR BOTH HORIZONTAL AND VERTICAL FLOWS.

(3) Static head for two-phase flow

The static head for two-phase flow can be evaluated based on the average density.

However, it is likely that the vertical piping will be filled with liquid instead of two-phase fluid during start-up or shutdown. It is therefore necessary to study the hydraulic balance, equipment design or operation procedure to allow unsteady slug flow.

(4) Improving flow pattern

As shown in section 4.1.2, the variable to improve flow pattern is limited to the pipe inside diameter, if the process operating conditions can not be changed.

When the pipe inside diameter is changed, both gas and liquid velocities will increase in proportion to the pipe cross-sectional area on the flow pattern map designated by superficial liquid and vapor velocities.

Therefore one can estimate the effect of pipe size change on the flow pattern map.

3.3.8 Special Requirements**(1) Maximum pressure drop**

The pressure drop should be limited within the available static head in cases where flashing should be avoided to maintain the process performance in good condition, for example, a gravity flow line provided with orifice or other flow meter.

$$h_s \geq \sum_i h_{f_i} \quad (\text{pipe, orifice, line, fittings and so on}) \quad (3)$$

Where :

h_s = static head (m)

h_{f_i} = friction heads for orifice, line, fittings and so on (m)

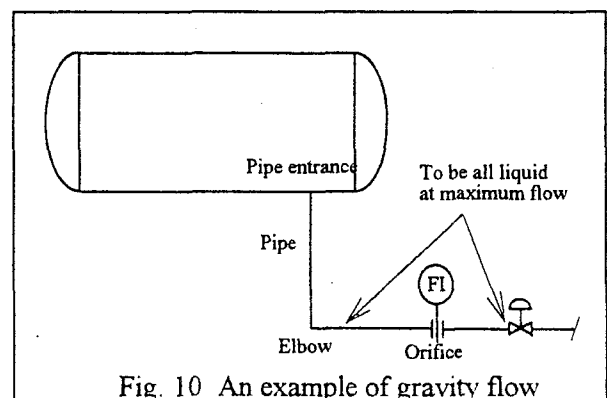


Fig. 10 An example of gravity flow

(2) Static electricity [API RP 2003]

This criterion is applicable to lines for tank truck loading. The maximum velocity in the loading piping should be less than the following.

$$V \cdot D \leq 0.5 \quad (\text{m}^2/\text{s}) \quad (4)$$

Where :

V = velocity in the down spout (m/s)

D = inside diameter of the down spout (m)

In addition to this restriction, the velocity shall never exceed 7 m/s. However, if the product contains a dispersed second phase, such as entrained water droplets, the velocity shall be restricted to 1 m/s.

Splash loading can contribute to the generation of electrostatic charge. The initial velocity shall be limited to about 1 m/s until the down spout outlet is submerged. The flow rate can then be increased within the limits specified above.

(3) Connections to vessels [API RP 551]

This criterion is applicable to lines with level instrument connections. Level instrument connections shall be made directly to vessels and not to process flow lines or nozzles (continuous or intermittent) unless the fluid velocity in the process line is less than 0.6 m/s.

3.3.9 Guidelines for Practical Line Sizing

The final line size shall be determined in the hydraulic design. In order to minimize routine studies, the following guidelines are useful for practical line sizing. Tables-5 to 7 show the practical pressure drops and practical velocities for each service.

(1) Table-5 Liquid service

Service	ΔP_{100} (kgf/cm ² /100m)	$V_{\text{practical}}$ (m/s)	Note
(a) Pump suction			
Boiling point liquid	0.05		(Note-1)
Subcooled liquid	0.08		(Note-2)
(b) Pump discharge	0.15 - 1.5	Economic Velocity	See 3.3.1
Carbon steel			
Stainless steel			
(c) Column draw-off	0.05	1.0	See item (2)
(d) Gravity flow - general service		1.0	(Note-3)
(e) Liquid to reboiler	0.05		(Note-4)
(f) Liquid to CV at BP	0.05		(Note-5)

(Note-1) Maintain 1.1 m/s or more for the FCC main column bottom to avoid the sediment of catalyst powder.

(Note-2) Subcool more than 27 °C below the boiling point.

(Note-3) Refer to HTFS Handbook FP3 and FM8.

(Note-4) Except for the furnace reboiler.

Maximum 0.18 kgf/cm²/100m for the thermosyphon reboiler depends on available static head.

(Note-5) The liquid at its boiling point (BP) should not be vaporized at the control valve(CV) inlet.

(2) Gravity flow from draw-off tray [15][16][17]

The maximum velocity in the draw-off nozzle shall either be lower than 1.3 m/s or the value calculated by the following equation, whichever is smaller:

$$V_m \leq 2.2\sqrt{H} \quad (H / D \geq 1.5) \quad (5)$$

Where :

V_m = maximum velocity in draw-off nozzle (m/s)

H = liquid depth over the top of draw-off nozzle (m)

D = draw-off nozzle size (m)

The line size shall also be checked so that the control valve size may not become larger than the line size.