

ENGINEERING STANDARD

FOR

PROCESS DESIGN OF FLARE AND BLOWDOWN SYSTEMS

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0. INTRODUCTION

"Process Design of Safeguarding Systems for OGP Processes" are broad and contain variable subjects of paramount importance. Therefore a group of process engineering standards are prepared to cover the subject.

This group includes the following Standards:

STANDARD CODE	STANDARD TITLE
IPS-E-PR-450	"Process Design of Pressure Relieving Systems Inclusive Safety Relief Valves"
IPS-E-PR-460	"Process Design of Flare and Blowdown Systems"
IPS-E-PR-470	"Process Design of Emergency Measures"
IPS-E-PR-480	"Process Design of Hazardous Area Classification"

This Standard covers:

"PROCESS DESIGN OF FLARE AND BLOWDOWN SYSTEMS"

In designing safeguarding systems for process plants, facilities should be provided for handling, directing and ultimately disposal of voluntary and involuntary gases and liquids. There are several options available to the process design engineer as to the selection of disposal systems. Once various disposal systems for each disposable material is selected, detail design is then undertaken.

In this Standard Practice Manual in addition to a general guideline for the selection of disposal systems, process design and evaluation of system components such as piping, knock-out drums, quench drums, seal drums, flare stacks and burning pits have been discussed.

1. SCOPE

This Standard Practice Manual covers process design and evaluation of relief systems for OGP process plants.

It includes network and related ancillary installations which are to handle and direct fluids discharged due to overpressure and/or operational requirements to a safe disposal system.

This Standard Practice Manual is primarily concerned with selection of disposal system, sizing of relief headers, sizing of flare systems and burning pits.

2. REFERENCES

Throughout this Standard the following standards and codes are referred to. The editions of these standards and codes that are in effect at the time of publication of this Standard shall, to the extent specified herein, form a part of this Standard. Changes in standards and codes that occur after the date of this Standard shall be mutually agreed upon by the Company and the Vendor/Consultant:

IPS (IRANIAN PETROLEUM STANDARDS)

IPS-E-GN-100	"Units"
IPS-E-PR-440	"Process Design of Piping Systems (Process Piping & Pipelines)", Parts 1-4.
IPS-E-PR-725	"Process Design of Plant Waste Water Sewer Systems".

API (AMERICAN PETROLEUM INSTITUTE)

"API Manual on Disposal of Refinery Wastes, Volume on Atmospheric Emissions".

NIOC (NATIONAL IRANIAN OIL COMPANY)

NIOC Engineering Practice Manual,
Section 14,

R.H. PERRY AND D. GREEN "Chemical Engineers Handbook", 6th. Ed., 1987, pp. 2-11.

3. DEFINITIONS & TERMINOLOGY

3.1 Atmospheric Discharge

Is the release of vapors and gases from pressure-relieving and depressuring devices to the atmosphere.

3.2 Autorefrigeration

Is the reduction in temperature as a result of pressure drop and subsequent flashing of light hydrocarbon liquids.

3.3 Back Pressure

Is the pressure that exists at the outlet of the pressure-relieving device because of pressure drop in the discharge system.

3.4 Balanced Safety/Relief Valve

Is a safety/relief valve that incorporates means for minimizing the effect of back pressure on the performance characteristics-opening pressure, closing pressure, lift, and relieving capacity.

3.5 Built-up Back Pressure

Is the pressure in the discharge header which develops as a result of flow after the safety-relief valve opens.

3.6 Closed Disposal System

Is a disposal system that is capable of containing pressures different from atmospheric pressure without leakage.

3.7 Conventional Safety/Relief Valve

Is a closed-bonnet pressure relief valve whose bonnet is vented to the discharge side of the valve. The valves performance characteristics-opening pressure, closing pressure, lift, and relieving capacity are directly affected by changes of the back pressure on the valve.

3.8 Critical Pressure Ratio

Is the result of the following relationship:

$$\frac{P_{cF}}{P_o} = [2 = (k + 1)]^{k/(k-1)} \quad (\text{Eq.1})$$

3.9 Flare

Is a means of safe disposal of waste gases by combustion. With an elevated flare, the combustion is carried out at the top of a pipe or stack where the burner and igniter are located. A ground flare is similarly equipped, except combustion is carried out at or near ground level. A burn pit differs from a flare in that it is primarily designed to handle liquids.

3.10 Flare Blow Off/Flame Lift-up

Is the lifting of flame front from the flare tip.

3.11 Flare Blow Out

Is the extinguishing of flare flame.

3.12 Mach Number

Is the ratio of vapor velocity to sonic velocity in that vapor at flowing conditions.

3.13 Open Disposal System

Is a disposal system that discharges directly from the relieving device to the atmosphere with no containment other than a short tail pipe.

3.14 Quenching

Is the cooling of a hot vapor by mixing it with another fluid or by partially vaporizing another liquid.

3.15 Super Imposed Back Pressure

Is the static pressure that exists at the outlet of a pressure relief device at the time the device is required to operate. It is the result of pressure in the discharge system coming from other sources and may be constant or variable.

3.16 Vent Stack

Is the elevated vertical termination of a disposal system that discharges vapors into the atmosphere without combustion or conversion of the relieved fluid.

4. SYMBOLS AND ABBREVIATIONS

A	=	Cross-sectional area, in (m ²).
A_{L1}	=	Vessel segment area occupied by slops and drain, in (m ²).
A_{L2}	=	Vessel segment area occupied by condensed liquid, in (m ²).
A_p	=	Pit area required to vaporize and burn liquid, in (m ²).
A_t	=	Total vessel cross-sectional area, in (m ²).
A_v	=	Vessel cross-section area available for vapor flow, in (m ²).
C	=	Drag coefficient.
d	=	Diameter of the inlet gas pipe, in (m).
d_i	=	Inside diameter of the line, in (m).
dp	=	Particle diameter, in (m).
f	=	Moody Friction Factor, $f=f_D=4f_F$, f_F =Fanning Friction Factor, f_D =Darcy Friction Factor.
g	=	Acceleration due to gravity, in (9.8 m/s ²).
G	=	Design mass flow, in (kg/s. m ²).
G_{ci}	=	Critical mass flow, in (kg/s.m ²).
h	=	Depth (maximum distance, that the inlet pipe is submerged), in (m).
H	=	Flare stack height, in (m).
h_{L1}	=	Vessel depth occupied by slops and drain, in (m).
h_{L2}	=	Vessel depth occupied by condensed liquid, in (m).
h_v	=	Vertical space for vapor flow, in (cm).
k	=	Ratio of specific heats, C_p/C_v for the vapor being relieved.
k₁	=	Dimensional constant equal to 0.076 mm/min.
K₂	=	Unit conversion factor equal to 60,000.

K_f	=	Factor representing frictional resistance to flow, (dimensionless).
l_e	=	Equivalent length of line, in (m).
L	=	Flare knock-out drum length, in (m).
L_f	=	Flame length, in (m).
L_{min}	=	Flare knockout drum minimum length required, in (m).
M	=	Molecular mass (weight) of the vapor or gas.
N	=	Line resistance factor, (dimensionless).
n	=	Polytropic exponent.
P_o	=	Upstream pressure, in (kPa absolute).
P_1	=	Pressure in the pipe at the exit or at any point or distance l downstream from the source, in (kPa absolute).
P_2	=	Pressure in reservoir into which pipe discharges, in [101 kPa (absolute) with atmospheric discharge].
P_{CF}	=	Critical-flow pressure, in (kPa absolute).
P_f	=	Pressure of the vapor just inside the flare tip, in (kPa absolute).
q_l	=	Rate of vaporization and burning of liquid, in (kg/s) (selected as equal to the rate of flashed liquid entering the pit).
q_s	=	Steam flow rate, in (kg/s).
q_v	=	Vapor relief rate, in (kg/s).
Q_v	=	Heat required to vaporize liquid, in (kJ/kg).
r	=	Radius.
R	=	Surface distance from the center of flare stack to the object under consideration, in (m).
RH	=	Relative humidity, in (percent).
S	=	Minimum distance from the midpoint of the flame to the object under consideration, in (m).
S_R	=	Linear regression rate of liquid surface, in (mm/min).
T_o	=	Upstream temperature, in (K).
T_f	=	Temperature of the vapor just inside the flare tip in (K).
U_d	=	Particle dropout velocity, in (m/s).
U_j	=	Exit gas velocity, in (m/s).
U_v	=	Vapor velocity, in (m/s).
U_∞	=	Lateral wind velocity, in (m/s);

Greek Letters

ρ_L (rho)	=	Density of liquid at operating conditions, in (kg/m ³)
ρ_V (rho)	=	Density of vapor at operating conditions, in (kg/m ³).
μ (mu)	=	Viscosity of gas, in (cP=1m Pa. s);
γ (tau)	=	Fraction of heat intensity transmitted through the atmosphere.
Φ (phi)	=	Heat release (LHV), in (kW).
Ψ (psi)	=	Allowable radiation level, in (kW/m ²).
θ (theta)	=	Liquid particle dropout time, in (s).
π (pi)	=	Constant figure equal to 3.1416.

5. UNITS

This standard is based on International System of Units, (SI) except where otherwise specified.

6. SELECTION OF BLOWDOWN SYSTEMS

6.1 General

While the various systems for the disposal of voluntary or involuntary vapor or liquid are mentioned below, the actual selection of a disposal system shall be conducted in accordance with the expected frequency, duration of operation, required capacity and fluid properties.

6.2 Blowdown System for Vapor Relief Stream

Systems for the disposal for voluntary and involuntary vapor discharges are:

- 1) To atmosphere
- 2) To lower pressure process vessel or system
- 3) To closed pressure relief system and flare
- 4) Acid gas flare

6.2.1 Vapor discharge to atmosphere

Vapor relief streams shall be vented directly to atmosphere if all of the following conditions are satisfied (for a complete discussion on the subject see API RP 521):

- 1) Such disposal is not in conflict with the present regulations concerning pollution and noise.
- 2) The vapor is effectively non-toxic and non-corrosive.
- 3) Vapor which is lighter than air or vapor of any molecular mass that is non-flammable, non-hazardous and non-condensable.
- 4) There is no risk of condensation of flammable or corrosive materials.
- 5) There is no chance of simultaneous release of liquid, apart from water.
- 6) Relief of flammable hydrocarbons direct to the atmosphere should be restricted to cases where it can be assured that they will be diluted with air to below the lower flammable limit. This should occur well before they can come in contact with any source of ignition.

The above condition can most easily be met if the vapors to be released have a density less than that of air. However, with proper design of the relief vent adequate dilution with air can be obtained in certain cases with higher density vapors. Methods of calculation are given in API RP 521 section 4.3.

Exceptions:

- 1) Vapor from depressuring valves shall be discharged to a closed pressure relief system.
- 2) Vapor which contains 1% H₂S or more by volume, shall be discharged to a closed pressure relief system.

6.2.2 Vapor discharge to lower pressure process vessel or system

Individual safety/relief valves may discharge to a lower pressure process system or vessel capable of handling the discharge. Although this type is rarely used, it is effective for discharges that contain materials which must be recovered.

6.2.3 Vapor discharge to closed pressure relief system and flare

In all cases where the atmospheric discharge of vapor to a lower pressure system is not permissible or practicable, vapor shall be collected in a closed pressure relief system which terminates in a flare, namely flare system. Where the concentration of H₂S is such that condensation of acid gas is probable, provision for a separate line, heat traced, shall be considered. In all cases, the installation of a closed pressure relief system shall result in a minimum of air pollution and the release of combustion products.

6.2.4 In process plants where H₂S free and H₂S containing stream are to be flared, consideration should be given to the installation of a separate header and flare stack assembly for the H₂S containing streams. The following provisions should be studied for the acid flare assembly:

- 1) Automatic injection of fuel gas down stream of H₂S pot in order to make the combustion stable.
- 2) Steam injection for smokeless operation shall not be considered for H₂S flare tip.
- 3) A common pilot igniter shall be used to ignite all flare stacks including the acid flare.
- 4) The H₂S flare header and subheaders shall be heat traced in order to prevent the condensation acid gas.

6.3 Blowdown System for Liquid Relief Stream

Systems for the disposal of voluntary and involuntary liquid discharges are:

- 1) To onsite liquid blowdown drum.
- 2) To lower pressure process vessel or system.
- 3) To oily water sewers only if the material will not cause hazardous conditions.
- 4) To pump suction if pump will not overheat or can withstand the expected temperature rise.
- 5) To burning pit.
- 6) To vaporizer

Thermal expansion relief valves may discharge small quantities of volatile liquid or vapor into the atmosphere, provided the valve outlet is in a safe location.

6.3.1 Liquid discharge to onsite liquid blowdown drum

The liquid shall be discharged to an onsite liquid blowdown drum which is capable of retaining the liquid discharged at the required liquid relief rate for a period of 20 minutes. This drum shall have a vapor discharge line to the closed pressure relief system.

6.3.2 Liquid discharge to lower pressure process vessel or system

The liquid shall be discharged to a lower pressure process vessel or system which is capable of handling the required liquid relief rate plus any flashed vapor.

6.3.3 Liquid discharge to oily water sewer

Liquid discharge to an oily water sewer shall be nonvolatile and nontoxic. The required liquid relief rate shall be within the oil removal capability of the oily water treating system.

6.3.4 Liquid discharge to pump suction

Required liquid relief shall discharge to an upstream liquid reservoir from which the pump takes suction. The liquid relief may discharge directly to the pump suction line if sufficient cooling is provided to prevent a temperature rise of the liquid recycled through the pump when the safety/relief valve opens or when a constant displacement pump is used.

6.3.5 Liquid discharge to burning pit

Liquid relief or voluntary liquid blowdown which need not be returned to the process or discharged to an oily water sewer, shall be discharged to a burning pit, if environmentally accepted.

6.3.6 Liquid discharge to vaporizer

The liquid shall be discharged to a vaporizer which is capable of vaporizing a liquid relief of no more than 5,000 kg/h.

7. DESIGN OF DISPOSAL SYSTEM COMPONENTS

Depending on the process plant under consideration, a disposal system could consist of a combination of the following items: piping, knock-out drum, quench drum, seal drum, flare stack, ignition system, flare tip, and burning pit.

7.1 Piping

7.1.1 General

In general, the design of disposal piping should conform to the requirements of ANSI / ASME B31.3 Installation details should conform to those specified in API Recommended Practice 520, Part II.

7.1.2 Inlet piping

The design of inlet piping should be in accordance with API-RP-521, Section 5.4.1.

7.1.3 Vapor relief header

The sizing should be in accordance with API-RP-521, Section 5.4.1.2 in conjunction with Tables 1 & 2 and Appendix A as a supplement to the above; and API-RP-520, Part I, Section 7 and Appendix C therein.

TABLE 1 - TYPICAL K_f VALUES FOR PIPE FITTINGS

FITTING	K_f	FITTING	K_f		
GLOBE VALVE, OPEN	9.7	90-DEGREE DOUBLE-MITER ELBOW	0.59		
TYPICAL DEPRESSURING VALVE, OPEN	8.5	SCREWED TEE THROUGH RUN	0.50		
ANGLE VALVE, OPEN	4.6	FABRICATED TEE THROUGH RUN	0.50		
SWING CHECK VALVE, OPEN	2.3	LATERAL THROUGH RUN	0.50		
180 DEGREE CLOSE-SCREWED RETURN	1.95	90-DEGREE TRIPLE-MITER ELBOW	0.46		
SCREWED OR FABRICATED TEE THROUGH BRANCH	1.72	45-DEGREE SINGLE-MITER ELBOW	0.46		
90-DEGREE SINGLE-MITER ELBOW	1.72	180-DEGREE WELDING RETURN	0.43		
WELDING TEE THROUGH BRANCH	1.37	45-DEGREE SCREWED ELBOW	0.43		
90-DEGREE STANDARD-SCREWED ELBOW	0.93	WELDING TEE THROUGH RUN	0.38		
60-DEGREE SINGLE-MITER ELBOW	0.93	90-DEGREE WELDING ELBOW	0.32		
45-DEGREE LATERAL THROUGH BRANCH	0.76	45-DEGREE WELDING ELBOW	0.21		
90-DEGREE LONG-SWEEP ELBOW	0.59	GATE VALVE, OPEN	0.21		
RATIO OF DIAMETERS					
CONTRACTION or ENLARGEMENT	0	0.2	0.4	0.6	0.8
CONTRACTION (ANSI)	—	—	0.21	0.135	0.039
CONTRACTION (SUDDEN)	0.5	0.46	0.38	0.29	0.12
ENLARGEMENT (ANSI)	—	—	0.9	0.5	0.11
ENLARGEMENT (SUDDEN)	1.0	0.95	0.74	0.41	0.11

TABLE 2 - TYPICAL FRICTION FACTORS AND CONVERSION FACTORS FOR CLEAN STEEL PIPE (BASED ON EQUIVALENT ROUGHNESS OF 0.046 mm)

CONVERSION FACTOR FOR EQUIVALENT LENGTH PER UNIT OF K_f		
DIAMETER NOMINAL PIPE SIZE (mm)	MOODY FRICTION FACTOR (f)	METERS
DN 50 SCHEDULE 40	0.0195	2.7
DN 80 " "	0.0178	4.36
DN 100 " "	0.0165	6.25
DN 150 " "	0.0150	10.2
DN 200-6 mm WALL	0.0140	14.7
DN 250 " "	0.0135	19.2
DN 300 " "	0.0129	24.0
DN 350 " "	0.0126	27.3
DN 400 " "	0.0123	31.88
DN 500 " "	0.0119	41.45
DN 600 " "	0.0115	56.67
DN 750 " "	0.0110	67.85
DN 900 " "	0.0107	83.33

Note:

The above friction factors and conversion factors apply at high Reynolds numbers, namely, above 1×10^6 for DN 600 and larger, scaling down to 2×10^5 for DN 50.

7.1.4 Liquid blowdown header

In order to reduce relief header loads and prevent surges due to two-phase gas/liquid flow as much as possible, it is advisable to direct all disposable liquids into a separate blowdown network.

Once maximum load and back pressure in each segment have been established, standard pipe sizing procedures are used (refer to IPS-E-PR-440).

Determination of back pressure would be as discussed in the section on discharge piping. The following shall also be taken into consideration:

- 1) Flashing of liquid at relief/safety valve discharge or along the network due to pressure drop and/or warm-up to ambient temperatures should be analysed.
- 2) Solids formation due to autorefrigeration and presence of high melting point liquids should be determined.
- 3) If flashing and autorefrigeration is possible, a temperature profile along the network should be established so that proper piping material selection and construction practices is undertaken.
- 4) The network should be self-draining and should not include pockets.
- 5) The network should be continuously purged by natural gas controlled through an orifice.
- 6) High liquid velocities should be watched for within the network (refer to IPS-E-PR-440).

7.1.5 Stress

The design should be in accordance with API-RP-521, Section 5.4.1.3, in conjunction with Table 2 as a supplement to the above.

7.1.6 Anchors, guides, and supports

The design should be in accordance with API-RP-521, Section 5.4.1.4; and ANSI / ASME B.31.3.

7.1.7 Drainage

Disposal system piping should be self-draining toward the discharge end. Pocketing of discharge lines should be avoided. Where pressure relief valves handle viscous materials or materials that can solidify as heat cool to ambient temperature, the discharge line should be heat traced. A small drain pot or drip leg may be necessary at low points in lines that can not be sloped continuously to the knockout or blowdown drum. The use of traps or other devices with operating mechanisms should be avoided.

7.1.8 Details

1) Safety/relief valve connection to the header

Normally, the laterals from individual relieving devices should enter a header from above.

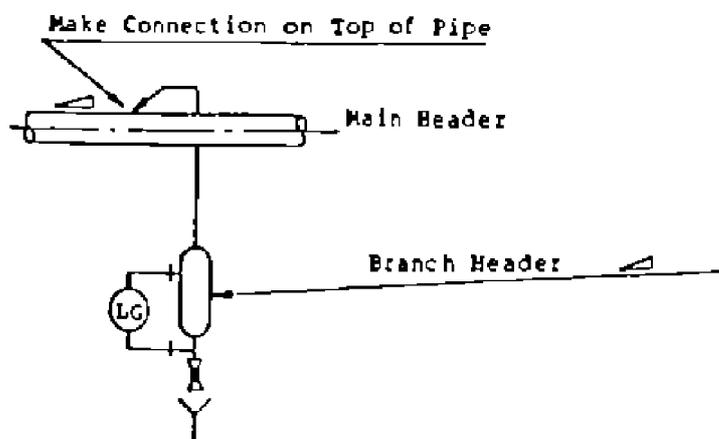
2) Safety/relief valves connection when installed below the relief header

Laterals leading from individual valves located at an elevation above the header should drain to the header. Locating a safety valve below the header elevation in closed systems should be avoided. Laterals from individual valves that must be located below the header should be arranged to rise continuously to the top of the header entry point. However, means should be provided to prevent liquid accumulation on the discharge side of these valves.

In this regard the following should be taken into consideration:

- a) For the branch header which must be connected to the main header from a lower level than the main header, e.g., sleeper flare piping, a drain pot must be installed. This is shown in Fig. 1.
- b) If a safety/relief valve must be installed below the flare header, the outlet line leading to the flare header shall be heat-traced from the safety/relief valve to their highest point. But the arrangement of safety/relief valve must be reviewed, as such, an arrangement is not permitted for safety/ relief valves which discharge a medium which can leave a residue.

The heat-tracing can be omitted if the safety/relief valve in question handles only products which vaporize completely, or do not condense at all, at the lowest ambient temperature.



DRAIN POT

Fig. 1

DRAIN POT SIZE:

Diameter the larger between twice the cross-sectional area of the branch header and pipe of DN 250.

Height minimum 800 mm.

3) Purge Point of Gas for Dry Seal

- a) A continuous fuel gas purge shall be installed at the end of the main header and the end of any major subheader. The fuel gas purge shall be controlled by means of a restriction orifice.
- b) Purge gas volume shall be determined such that a positive pressure is maintained and air ingress is prevented.

4) Insulation of Flare Line

Normally insulation of flare line (including outlet line of safety/relief valve) is not required except for personnel protection.

But to avoid hydrate formation or ice accumulation, etc., within the flare line the use of insulation or heat tracing shall be considered.

5) Location of Safety/Relief Valve

More than one piece of equipment may be protected by a common safety/relief valve, provided they are connected by a line of sufficient size and that no block valve exists on the connecting lines.

6) Valves on Inlet/Outlet Line of Safety/Relief Valve

All safety relief valves must have block valves on the inlet and outlet to facilitate maintenance. The block valves must be locked open. Safety valves discharging to the atmosphere shall not have block valves on the outlet. A bypass line with a valve shall be provided for each safety valve.

7) Provision for Installation of Drain Holes

Where individual valves are vented to the atmosphere, an adequate drain hole [a nominal pipe size of DN 15 is usually considered suitable] should be provided at the low point to ensure that no liquid collects downstream of the valve. The vapor flow that occurs through this hole during venting is not generally considered significant, but each case should be checked to see if the drain connection should be piped to a safe location. Vapors escaping from the drain hole must not be allowed to impinge against the vessel shell, since accidental ignition of such vent streams can seriously weaken the shell.

8) Angle Entry Into the Relief Header

The use of angle entry an-entry at 45 degrees (0.79 radian) or even 30 degrees (0.52 radian) to the header axis-for laterals is much more common in relieving systems than in most process piping systems.

9) Installation of Valves and Blinds in Relief Headers

Means (valve and blind) must be provided to isolate each unit from the flare system for safety and maintenance. Extreme caution must be exercised in their use to ensure that equipment which is operating is not isolated from its relieving system. Valves in the header system, if used should be mounted so that they cannot fail in the closed position (for example, a gate falling into its closed position).

10) Slope of Flare Header

A slope of 1 m in 500 m is suggested for the flare header.

11) Absorption of Thermal Expansion in Headers by Looped Pipes

- a) As a rule, headers shall be designed so that thermal expansion generated in headers can be absorbed by the bent parts of the headers. In other words, the piping route of headers shall incorporate several bends.
- b) If thermal expansion cannot be absorbed by the above method, absorption by looped pipes shall be considered. Looped parts shall have no drain pocket.

12) Absorption of Thermal Expansion by Expansion Joints

- a) As a rule, no expansion joints shall be used. The use of expansion joints is limited to the case in which thermal expansion cannot be absorbed by pipes alone because of a short route, e.g., the route between the seal drum (or knock out drum) and the flare stack.

- b) Drain pipes shall be installed at bellows or other concave parts where drain is likely to remain.
- c) The conditions for selecting bellows (design condition, materials) shall be specified clearly.

13) Solids Formation

The possibility of solids forming within the disposal system must be studied considering all related aspects, such as hydrate formation, water or heavy hydrocarbon presence, auto-refrigeration, etc. Consideration should be given to separate disposal system so that the possibility of solids formation is eliminated.

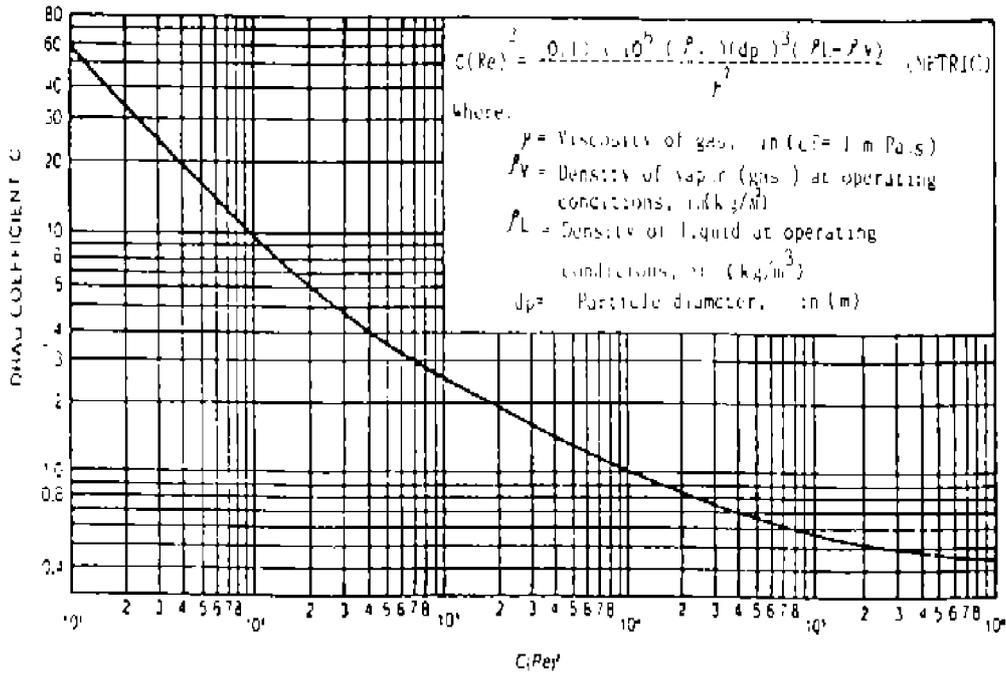
7.2 Sizing a Knock-out Drum

See Appendix B and Figs. 2 & 3. and Table 3 in Appendix B.

7.3 Quench Drum

7.3.1 General

A quench drum is provided as a means of preventing liquid hydrocarbon condensation in the flare system, to reduce flare capacity requirements, or to prevent discharge of condensible hydrocarbons to the atmosphere. In some cases, it serves the additional purpose of reducing the maximum temperature of flare gases and hence minimizing thermal expansion problems in the mechanical design of flare headers. The quench drum functions by means of a direct contact water spray arrangement which condenses entering heavy hydrocarbon vapors. Condensed hydrocarbons and effluent water are discharged through a seal to the sewer or pumpout to slop tankage. On the other hand, uncondensed hydrocarbon vapors are vented to the flare or to the atmosphere. Fig. 4 presents a typical quench drum.



DETERMINATION OF DRAG COEFFICIENT

Fig. 2

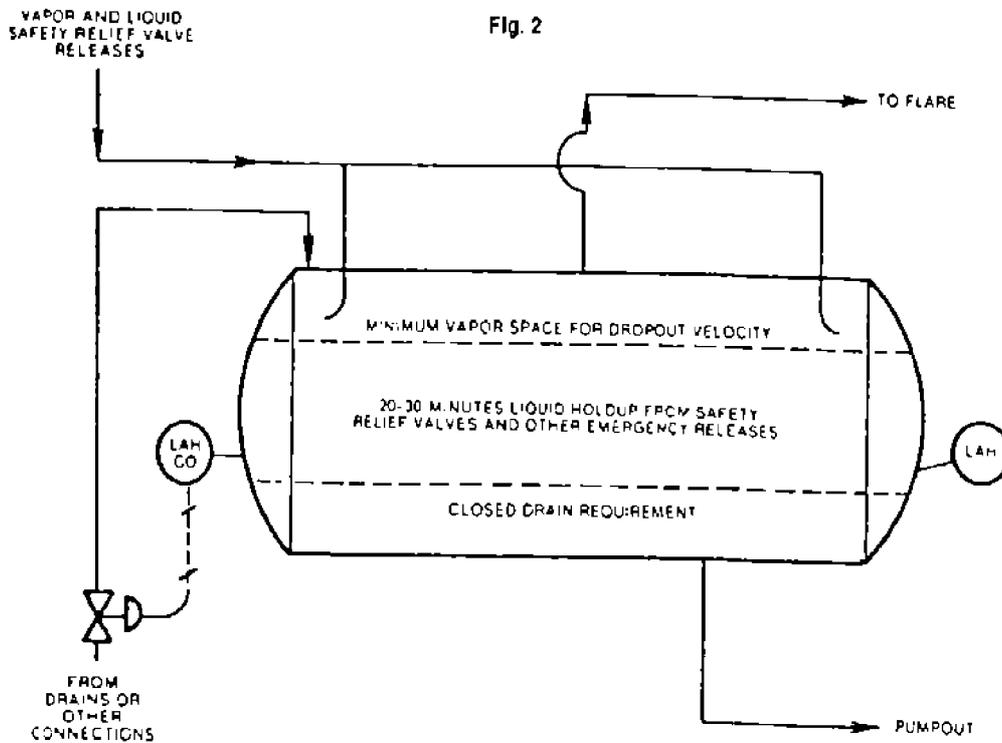
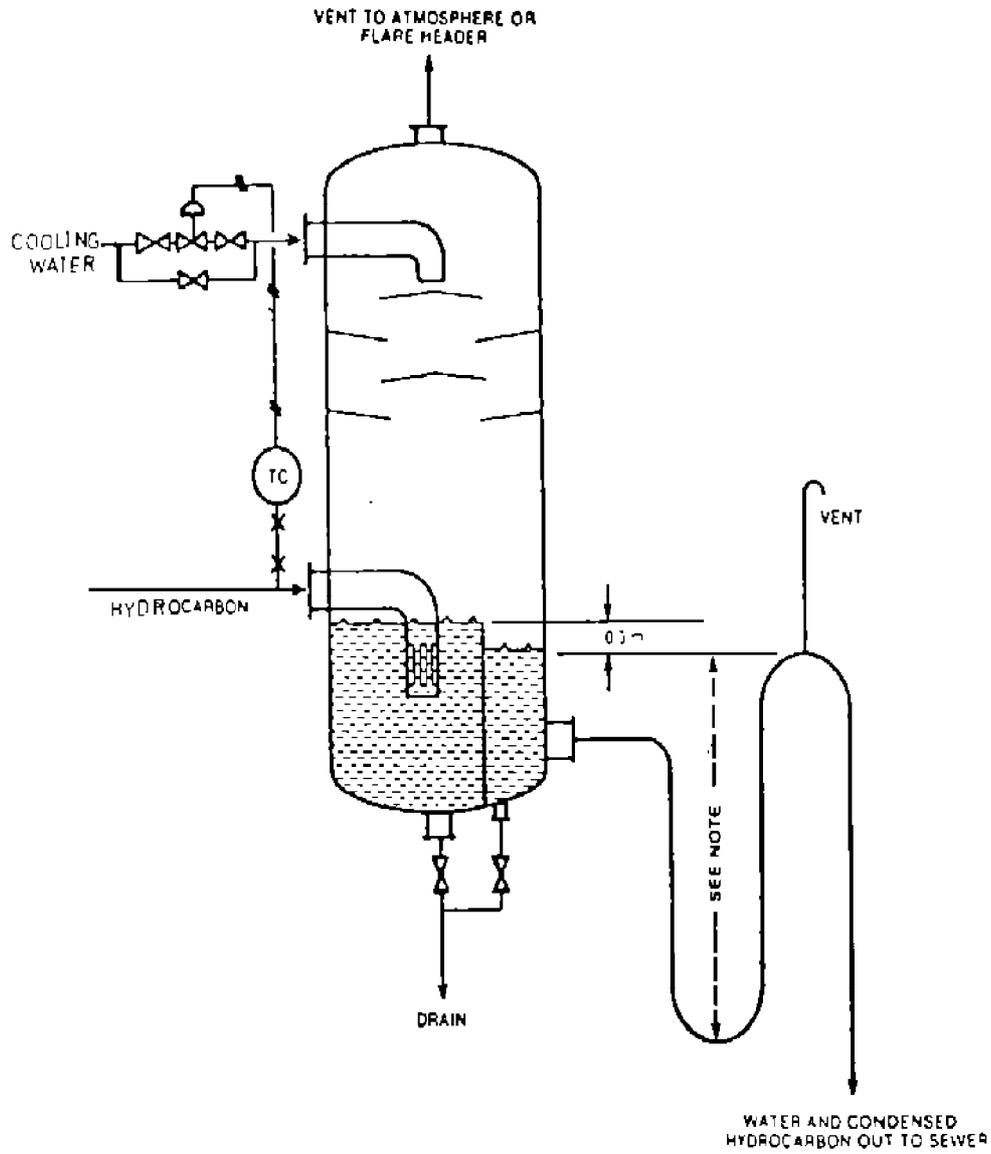


Fig. 2

FLARE KNOCK-OUT DRUM

Fig. 3



QUENCH DRUM

Fig. 4

Notes:

- 1) It is suggested that the sewer seal be designed for a minimum of 175 percent of the drum's maximum operating pressure.
- 2) Proper destination of liquid effluent should be investigated in case it contains toxic or hazardous materials.
- 3) Criteria for venting to atmosphere should be considered.

7.3.2 Details

- a) The quench drum shall have a design pressure capable of withstanding the maximum back pressure. Minimum design pressure is 350 kPa gage.
- b) Water requirements are normally based on reducing gas and liquid outlet temperatures to about 50°C. Selection of the optimum temperature is based on considerations of temperature and composition of entering streams, and the extents to which subsequent condensation of effluent vapors downstream of the drum can be tolerated.

It is generally assumed that no more than 40-50 percent of the liquid fed will be vaporized. The water supply should be taken from a reliable water system. If a recirculating cooling water system is used, then the circulating pumps and cooling water basin must have adequate capacity to supply the maximum quench drum requirements for 20 minutes.

The seal height in the liquid effluent line (assuming 100% water) is sized for 175% of the maximum operating pressure, or 3 meters, whichever is greater.

7.4 Sizing a Seal Drum

Sizing a seal drum and design details should be in accordance with API-RP-521, Sections 5.4.2.2 and 5.4.2.4; and API-RP-2001, Section 3.14.3.

For treating sour water discharge from seal drums refer to IPS-E-PR-725.

7.5 Flares

7.5.1 General

Flare systems provide for the safe disposal of gaseous refinery wastes. Depending on local environmental constraints, these systems can be used for:

- 1) Extensive venting during startup or shutdown.
- 2) Venting of excess Process Plant gas.
- 3) Handling emergency releases from safety valves, blowdown, and depressuring systems.

Designs will vary considerably, depending upon the type of connected equipment and the complexity of the overall system.

A flare system generally consists of an elevated stack, means to maintain burning conditions at the top of stack and means to prevent flashback within the system.

7.5.2 Sizing

The sizing of flares requires determination of the required stack diameter and the required stack height.

Other factors governing sizing are wind effect and dispersion.

Since the flare tip is open to the atmosphere, high gas velocities are expected at this point. Very high tip velocities cause a phenomenon known as blow-off where the flame front is lifted and could eventually turn into a blow-out. Very low velocities could damage the flare tip due to high heat intensities and smoking. In this case ingress of air in the system and creation of a flammable mixture is possible. Therefore, determination of the right flare diameter is important as far as operation of the system is concerned.

The location and height of flare stacks should be based upon the heat release potential of a flare, the possibility of personnel exposure during flaring, and the exposure of surrounding plant equipment. There are exposure limitations set forth which must be taken into consideration. This in effect fixes the distance between the flame and the object. Now if there are limitations on the location (distance), then the stack height can be calculated, otherwise an optimum trade off between height and distance should be applied.

Wind velocity, by tilting the flame in effect changes the flame distance and heat intensity. Therefore, its effect should be considered in determining the stack height.

If the flare is blown-out (extinguished), or if there are environmental hazards associated with the flare output, the possibility of a hazardous situation down wind should be analysed.

a) Diameter

Flare stack diameter is generally sized on a velocity basis, although pressure drop should be checked. Depending on the volume ratio of maximum conceivable flare flow to anticipated average flare flow, the probable timing, frequency, and duration of those flows, and the design criteria established for the project to stabilize flare burning, it may be desirable to permit a velocity of up to 0.5 Mach for a peak, short-term, infrequent flow, with 0.2 Mach maintained for the more normal and possibly more frequent conditions. Smokeless flares should be sized for the conditions under which they are to operate smokelessly.

The formula relating velocity (as Mach number) to flare tip diameter can be expressed as follows:

$$Mach = (11.61) (10^{-2}) \frac{q_v}{p_f \cdot d_i^2} \sqrt{\frac{T_f}{kM}} \tag{Eq. 2}$$

Pressure drops as large as 14 kilopascals have been satisfactorily used at the flare tip. Too low a tip velocity can cause heat and corrosion damage. The burning of the gases becomes quite slow, and the flame is greatly influenced by the wind. The low-pressure area on the downwind side of the stack may cause the burning gases to be drawn down along the stack for 3 meters or more. Under these conditions, corrosive materials in the stack gases may attack the stack metal at an accelerated rate, even though the top 2.4-3 meters of the flare is usually made of corrosion-resistant material.

b) Height

The flare stacks height is generally based on the radiant heat intensity generated by the flame.

The following equation may be used to determine the distance required between a location of atmospheric venting and a point of exposure where thermal radiation must be limited:

$$S = \sqrt[4]{\frac{q}{F}} \tag{Eq. 3}$$

The factor F allows for the fact that not all the heat released in a flame can be released as radiation.

Measurement of radiation from flames indicate that the fraction of heat radiated (radiant energy per total heat of combustion) increases toward a limit, similar to the increase in the burning rate with increasing flame diameter.

Data from the U.S Bureau of Mines for radiation from gaseous-supported diffusion flames are given in Table 4.

TABLE 4 - RADIATION FROM GASEOUS DIFFUSION FLAMES

GAS	BURNER DIAMETER (CENTIMETERS)	($\frac{\text{RADIATIVE OUTPUT}}{\text{THERMAL OUTPUT}}$) × 100
HYDROGEN	0.51	9.5
	0.91	9.1
	1.90	9.7
	4.10	11.1
	8.40	15.6
	20.30	15.4
	40.60	16.9
BUTANE	0.51	21.5
	0.91	25.3
	1.90	28.6
	4.10	28.5
	8.40	29.1
	20.30	28.0
	40.60	29.9
METHANE	0.51	10.3
	0.91	11.6
	1.90	16.0
	4.10	16.1
	8.40	14.7
NATURAL GAS (95 PERCENT CH ₄)	20.30	19.2
	40.60	23.2

These data apply only to the radiation from a gas. If liquid droplets of hydrocarbon larger than 150 micrometers in size are present in the flame, the values in Table 4 should be somewhat increased.

The fraction of heat intensity transmitted, τ is used to correct the radiation impact. It can be calculated from the following relationship:

$$\tau = 0.79 \frac{100}{RH}^{\pm 1=16} \frac{30.5}{S}^{\pm 1=16} \tag{Eq. 4}$$

This equation is strictly applicable under the following conditions: luminous hydrocarbon flame radiating at 1227°C, 27°C dry bulb ambient temperature, relative humidity more than 10%, distance from the flame between 30 and 150 m, but it can be used to estimate the order of magnitude of under a wide range of conditions. This equation should prove adequate for most flare gases, except H₂ and H₂S which burn with little or no luminous radiation.

The allowable radiation level, Ψ is given in Table 5.

TABLE 5 - RECOMMENDED DESIGN FLARE RADIATION LEVELS EXCLUDING SOLAR RADIATION

PERMISSIBLE DESIGN LEVEL	
KILOWATTS PER SQUARE METER	CONDITIONS
15.77	HEAT INTENSITY ON STRUCTURES AND IN AREAS WHERE OPERATORS ARE NOT LIKELY TO BE PERFORMING DUTIES AND WHERE SHELTER FROM RADIANT HEAT IS AVAILABLE, FOR EXAMPLE, BEHIND EQUIPMENT
9.46	VALUE OF AT DESIGN FLARE RELEASE AT ANY LOCATION TO WHICH PEOPLE HAVE ACCESS, FOR EXAMPLE, AT GRADE BELOW THE FLARE OR ON A SERVICE PLATFORM OF NEARBY TOWER. EXPOSURE MUST BE LIMITED TO A FEW SECONDS, SUFFICIENT FOR ESCAPE ONLY.
6.31	HEAT INTENSITY IN AREAS WHERE EMERGENCY ACTIONS LASTING UP TO 1 MINUTE MAY BE REQUIRED BY PERSONNEL WITHOUT SHIELDING BUT WITH APPROPRIATE CLOTHING
4.73	HEAT INTENSITY IN AREAS WHERE EMERGENCY ACTIONS LASTING SEVERAL MINUTES MAY BE REQUIRED BY PERSONNEL WITHOUT SHIELDING BUT WITH APPROPRIATE CLOTHING.
1.58	VALUE OF AT DESIGN FLARE RELEASE AT ANY LOCATION WHERE PERSONNEL ARE CONTINUOUSLY EXPOSED.

Note:

On towers or other elevated structures where rapid escape is not possible, ladders must be provided on the side away from the flare, so the structure can provide some shielding when is greater than 6.31 kilowatts per square meter.

As for the effect of radiation level on humans it should be noted that the allowable radiation level is a function of length of exposure. Table 6 gives exposure times necessary to reach the pain threshold.

TABLE 6 - EXPOSURE TIMES NECESSARY TO REACH THE PAIN THRESHOLD

RADIATION INTENSITY	TIME TO PAIN THRESHOLD (SECONDS)
KILOWATTS PER SQUARE METER	
1.74	60
2.33	40
2.90	30
4.73	16
6.94	9
9.46	6
11.67	4
19.87	2

The correction for the location of the flame center will be quite significant when radiation levels are examined. Flame length varies with emission velocity and heat release.

Information on this subject is limited and is usually based on visual observations in connection with emergency discharges to flares. Fig. 5 gives flame length versus heat release.

c) Wind effect

Another factor to be considered is the effect of wind in tilting the flame, thus varying the distance from the center of the flame, which is considered to be the origin of the total radiant heat release, with respect to the plant location under consideration. A generalized curve for approximating the effect of wind is given in Fig. 6.

d) Dispersion

Where there is concern about the resulting atmospheric dispersion if the flare were to be extinguished, reference should be made to the API Manual on Disposal of Refinery Wastes, Volume on Atmospheric Emissions for calculating the probable concentration at the point in question.

A sample calculation has been presented in Appendix D.

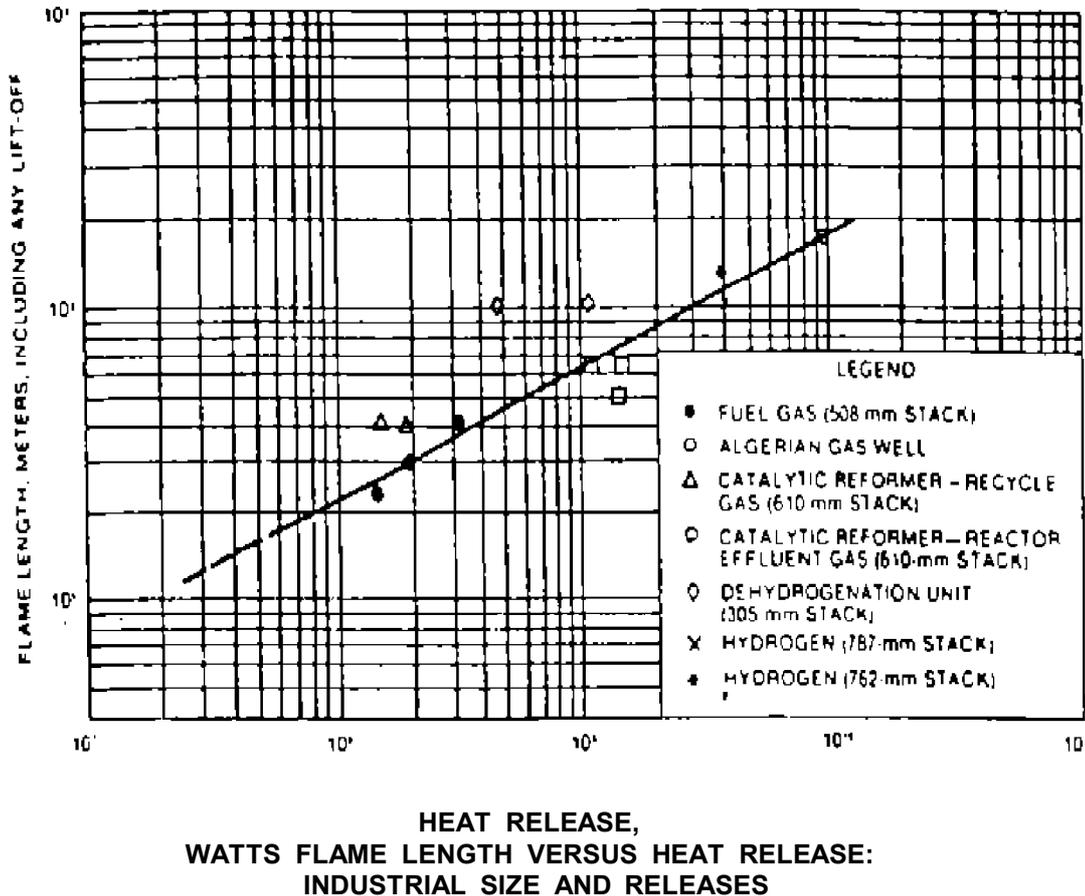
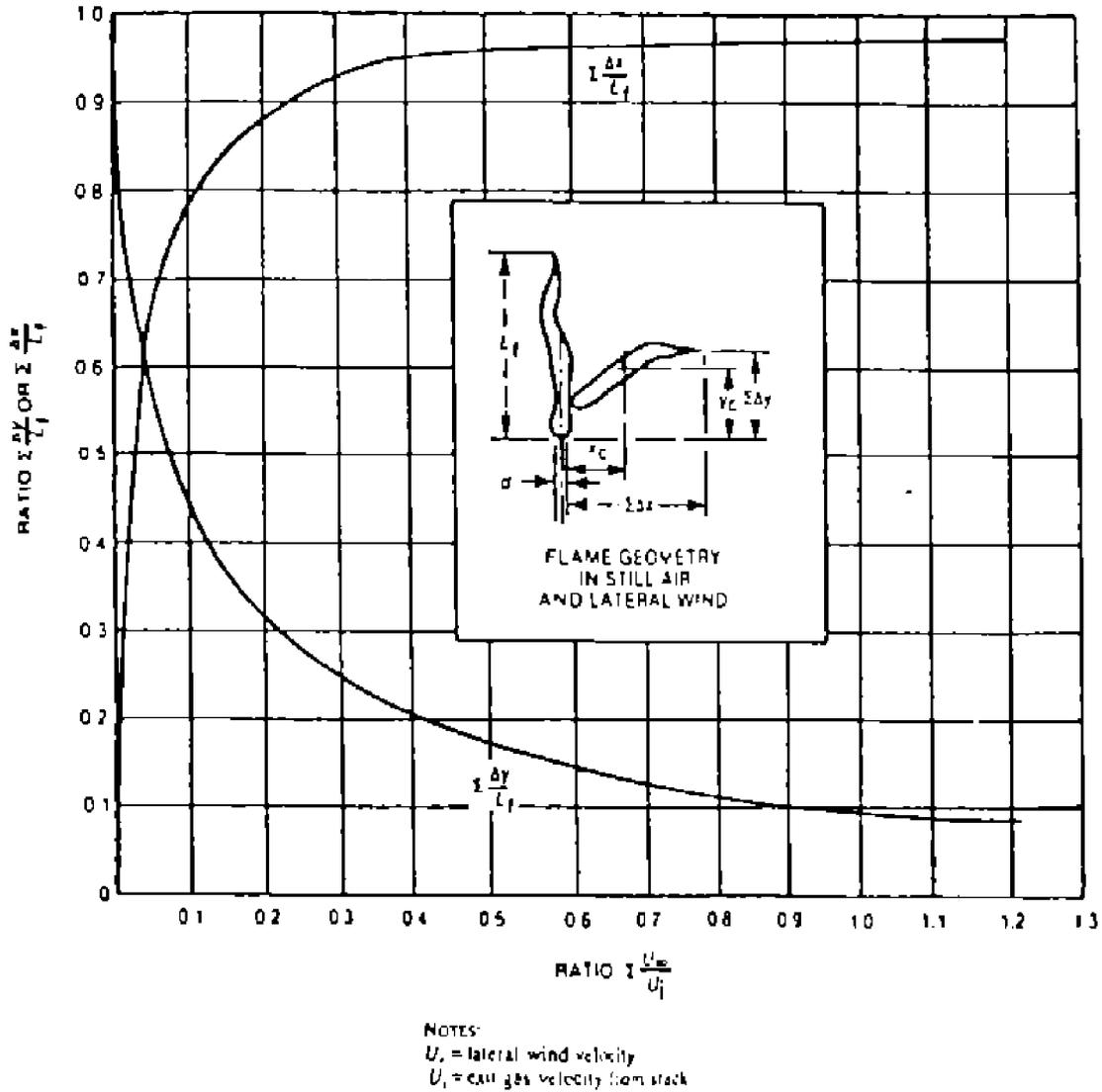


Fig. 5

Note:

Multiple points indicate separate observations or different assumptions of heat content.



APPROXIMATE FLAME DISTORTION DUE TO LATERAL WIND ON JET VELOCITY FROM FLARE STACKS

Fig. 6

7.5.3 Design details

1) Smokeless Flares

Smoke-free operation of flares can be achieved by various methods, including steam injection, injection of high pressure waste gas, forced draft air, operation of flares as a premixed burner, or distribution of the flow through many small burners.

The most common type of smokeless flare involves steam injection.

The assist medium mass requirements are low for steam and fuel gas because of their high velocity relative to the flare gas. Typical values for steam or fuel gas are from 0.20 to 0.50 kilograms of assist gas per kilograms of hydrocarbon flow.

The following equation predicts steam use for a given hydrocarbon molecular mass (weight) gas to be burned in a smokeless flare.

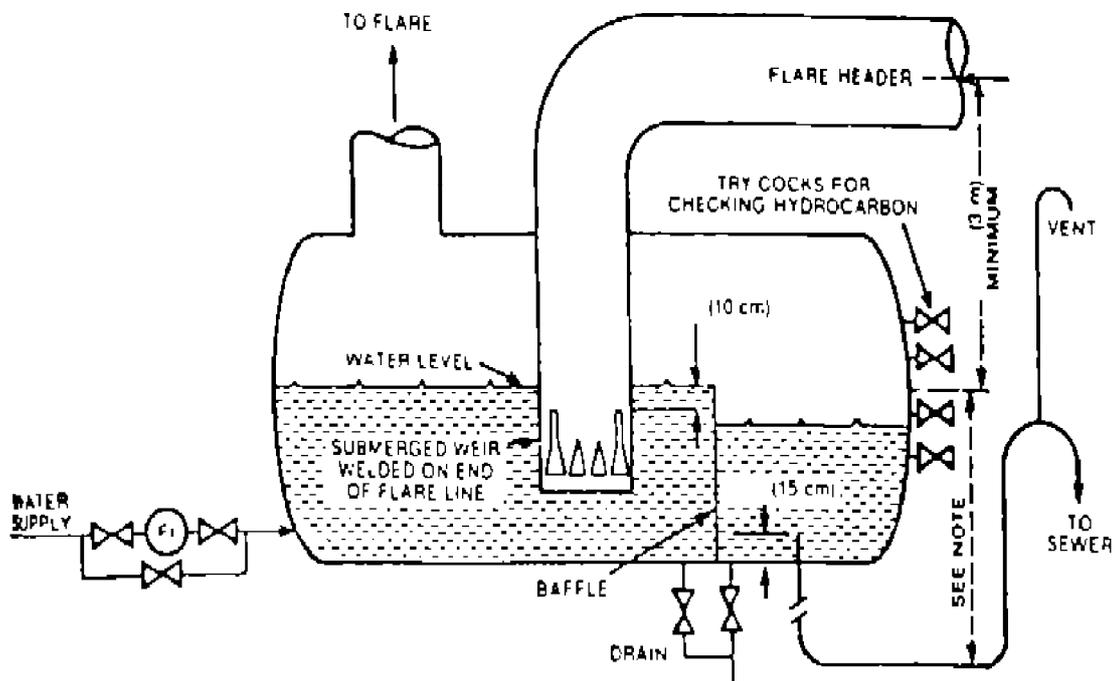
$$q_s = q_v [0.68 - (10.8/M)] \tag{Eq. 5}$$

2) Flashback Protection

The most common method of preventing propagation of flame into the flare system due to entry of air is the installation of a seal drum as depicted in Fig. 7. Flame arresters are occasionally used for flashback protection; however, they are subject to plugging, and their application is limited.

Alternatively, continuous introduction of purge gas can be used to prevent flash back. A safe condition exists in situations involving hydrocarbon air mixtures if a positive flow of oxygen free gas is maintained, allowing the oxygen concentration to be no greater than 6 percent at a point 7.6 meters from the flare tip. The injection rate should be controlled by a fixed orifice to ensure that supply remains constant and is not subject to instrument malfunction or maladjustment.

Molecular seals can be used to minimize purge gas rates.



FLARE STACK SEAL DRUM

Fig. 7

Note:

It is suggested that the sewer seal be designed for a minimum of 175 percent of the drum's maximum operating pressure.

3) Ignition

To ensure ignition of flare gases, continuous pilot with a means of remote ignition are recommended for all flares. The most commonly used type of igniter is the flame-front propagation type, which uses a spark from a remote location to ignite a flammable mixture.

Pilot igniter controls are located at a safe distance from the base of elevated flares and at least 30 meters from ground flares.

It is recommended that a low pressure alarm for the pilot gas be provided so that the operator in the control room becomes aware of pilot blow out.

Reliable pilot operation under all wind and weather conditions is essential. Flaring operations are for the most part intermittent and non-scheduled. The flare must be instantly available for full emergency duty to prevent any possibility of a hazardous or environmentally offensive discharge to the atmosphere. Wind-shields and flame-retention devices may be used to ensure continuous piloting under the most adverse conditions.

4) Fuel System

Fuel gas supply to the pilots and igniters must be highly reliable. Since normal plant fuel sources may be upset or lost, it is desirable to provide a backup system connected to the most reliable alternative fuel source, with provision for automatic cut-in on low pressure. Use of waste gas with low energy content or with unusual burning characteristic should be avoided. Parallel instrumentation for pressure reduction is frequently justifiable. The flare fuel system should be carefully checked to ensure that hydrates cannot present a problem. Because of small lines long exposed runs, large vertical rises up the stack, and pressure reductions, use of a liquid knockout pot or scrubber after the last pressure reduction is frequently warranted. If at all feasible in terms of distance, relative location, and cost, it is considered good practice to install a low-pressure alarm on the fuel supply after the last regulator or control valve so that operators will be warned of any loss of fuel to the pilots.

5) Fired or Endothermic Flares

When low heating value gases are to be sent to a flare stack, fired or endothermic flare are used (Sulfur plant tail gas presents an example).

Generally if the heating value of the gas to be flared is less than 4280 kJ/m^3 a fired flare with a high heating value assist gas may be required for complete combustion.

6) Location

The location of flares in the vicinity of tall refinery equipment should be examined. Flames or hot combustion products can be carried by the wind, which could cause problems and create hazards to personnel working on these elevated structures at the time of a flare release. As discussed in the section on sizing, flare height and distance are dependent on radiation intensity. When either the height or the distance from the plant of a flare is fixed the other can be determined. Usually there are constraints on the distance, therefore stack height is calculated. If there are no constraints on the distance and flare height is to be determined, the following guideline is recommended.

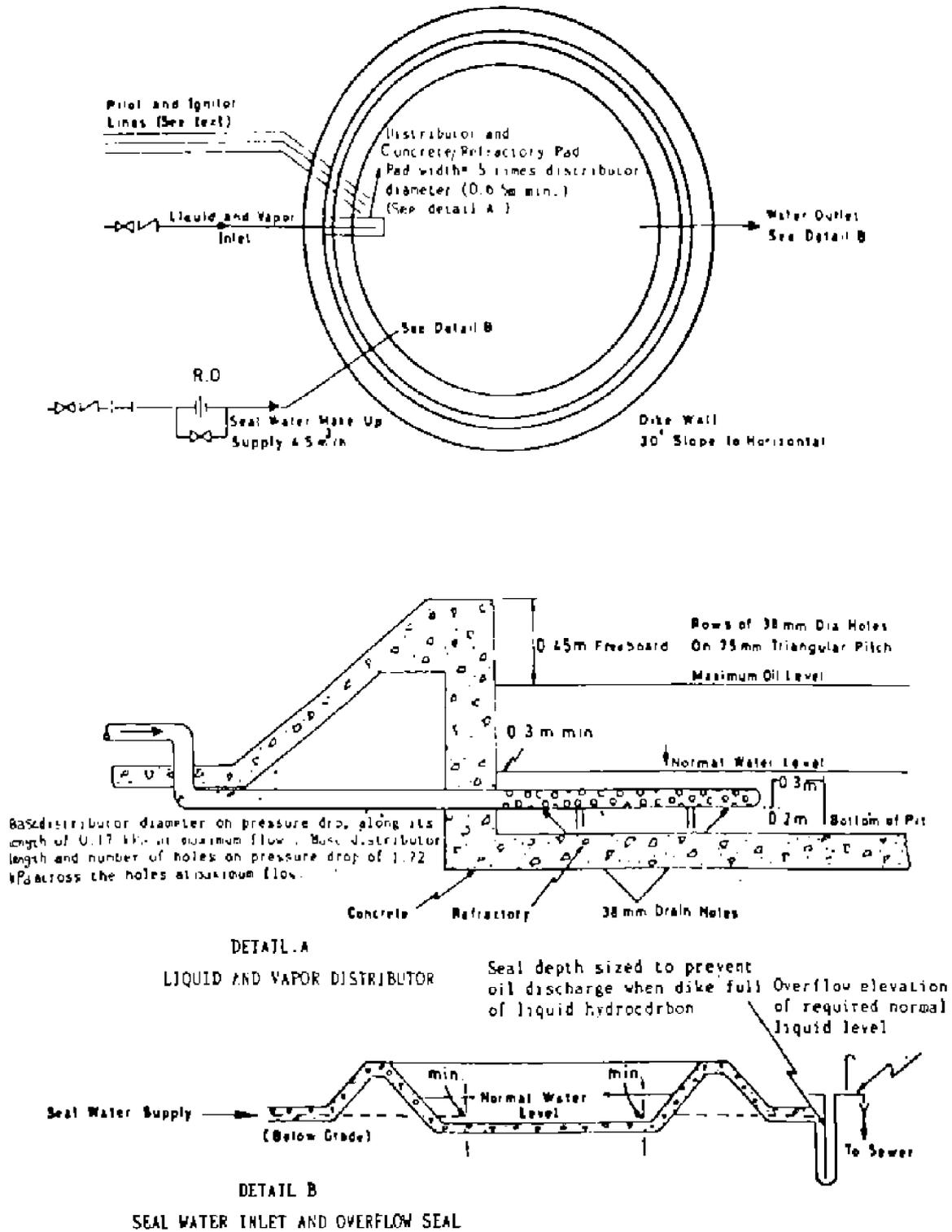
For stack heights less than 23 meters a distance of 91 meters, and for stack heights greater than 23 meters a distance of 61 meters from the plant is considered (see GPSA, Section. 2.1).

7) Due consideration should be given to installation of flow measuring equipment on the flare system. Specifically sub-headers handling relief loads from individual units shall be provided with proper flow elements.

7.6 Burning Pits

Burning pit flares can handle flammable liquids or gases or mixtures of the two. A typical design is shown in Fig. 8. In this figure a circular pit is illustrated, but any convenient shape may be used.

The burning pit is simply a shallow earth or concrete surfaced pool area enclosed by a dike wall, a liquid/vapor inlet pipe through the wall, and provided with pilot and ignitor. While the design basis flow is adequate for handling emergency releases, a more conservative approach is recommended for continuous flaring services, incorporating up to twice the calculated pit area.



TYPICAL BURNING PIT

Fig. 8

7.6.1 Burning pit flare sizing

The burning pit area is sized to provide sufficient surface to vaporize and burn liquid at a rate equal to the maximum incoming liquid rate. The calculation procedure is as follows:

- 1) Determine the linear regression rate of the liquid surface (i.e. the rate at which the liquid level would fall as a result of vaporization by radiant heat from the burning vapor above it, assuming no addition of incoming liquid):

$$S_R = K_1 \frac{Q_v q_1}{L} \quad (\text{Eq. 6})$$

- 2) Determine the pit area necessary to vaporize and burn liquid at a rate equal to the liquid input rate:

$$A_p = K_2 \frac{L}{S_R} \quad (\text{Eq. 7})$$

- 3) The dike wall height above the water level is selected to provide hollow capacity for the largest liquid release resulting from a single contingency during 30 minutes, plus 460 mm free board. The liquid rate is based on the actual flashed liquid entering the pit, assuming no burning or further vaporization in the pit. The height of the dike wall above the water level should not however, be less than 1.20 meters.

7.6.2 Spacing of burning pit flares

Spacing is based upon radiant heat consideration at maximum heat release, using a simplified calculation procedure, as follows:

$$S = \frac{q}{F} \quad (\text{Eq. 8})$$

This equation has been described in the section on flare sizing.

Note that in this equation absorption of radiation by surrounding air is neglected.

Also the fraction of heat radiated, as shown in Table 4 refers to light gases, but in burning pits combustion of liquid is under consideration; Therefore, good engineering judgement should be exercised in evaluating the effect of this factor when determining the distance.

The center of the flame is assumed to be 1.5 pool diameters from the center of the pool, in the direction of the point where radiant heat density is being considered. This assumption is used to allow for flame deflection by wind.

Although permissible radiant heat densities are given in Table 5, note that its value at the property line must not exceed 1.60 kilowatts per square meter.

In addition, the following minimum spacings apply to burning pits:

- 150 meters from property lines, roadways, or any process or storage facilities.
- 60 Meters from any source of ignitable hydrocarbons, such as separators, or floating roof tanks.

Valves in the inlet, seal water and pilot gas lines should be located according to permissible radiant heat densities for personnel. Piping to the burning pit should be suitably protected against flame impingement (e.g., by installation below grade).

In designing the burning pit all personnel and equipment safety precautions should be observed.

APPENDICES

APPENDIX A

VAPOR RELIEF HEADER SIZING

1) Calculate M (number of velocity heads).

$$M = \frac{L \cdot k_r}{d_i} \quad (Eq. A1)$$

where:

- f = Moody factor (dimensionless).
- L = length of equivalent pipe, in meters.
- d_i = internal diameter of pipe, in meters.
- k_r = factor representing friction resistance to flow, dimensionless. (see section 2.1.2)

2) Calculate P_1/P_0 or P_1/P_2 .

where:

- P_1 = pressure in reservoir into which pipe discharges
- P_0 = pressure at the upstream source, in kilopascals absolute.
- P_2 = pressure in the pipe at the exit or at any point distance downstream from the source, in kilopascals absolute.

3) Calculate G_c .

$$G_c = 6.77P_c \left(\frac{M}{T_0} \right)^{0.5} \quad (Eq. A.2)$$

where:

- G_c = critical mass flux, in kilograms per second per square meter.
- M = molecular mass (weight) of the vapor.
- T_0 = upstream temperature, in Kelvins.

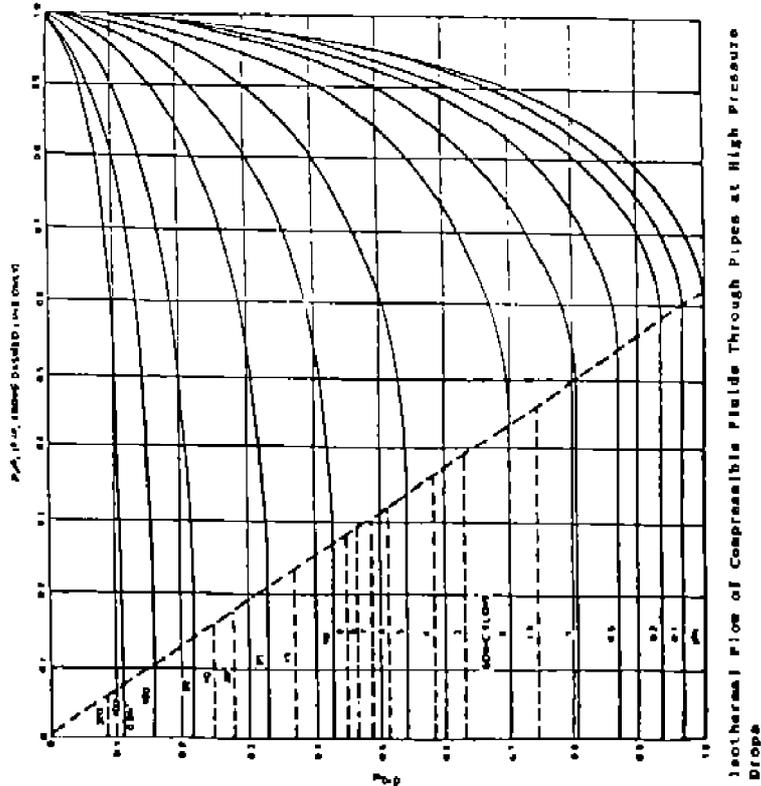
4) From P_1/P_0 or P_1/P_2 and M , read G/G_c .

5) Calculate G in kilograms per second per square meter.

Calculate q_v .

where:

- $q_v = G \cdot A$ (Cross-sectional area of pipe, in square meters).



APPENDIX B
SIZING A KNOCK-OUT DRUM

Sizing a knock-out drum is generally a trial-and-error process. First, the drum size required for liquid entrainment separation is determined. Liquid particles will separate when the residence time of the vapor or gas is equal to or greater than the time required to travel the available vertical height at the dropout velocity of the liquid particles and the vertical gas velocity is sufficiently low to permit the liquid droplet to fall. This vertical height is usually taken as the distance from the liquid surface. The vertical velocity of the vapor and gas must be low enough to prevent large slugs of liquid from entering the flare. Since the flare can handle small-sized liquid droplets, the allowable vertical velocity in the drum may be based on that necessary to separate droplets from 300 to 600 micrometers in diameter. The dropout velocity of a particle in a stream is calculated as follows:

$$U_d = 1.15 \sqrt{\frac{g \cdot d_p (\rho_L - \rho_v)}{\rho_v (C)}} \quad (\text{Eq. B.1})$$

This basic equation is widely accepted for all forms of entrainment separation.

The second step in sizing a knock-out drum is to consider the effect any liquid contained in the drum may have on reducing the volume available for vapor/liquid disengagement. This liquid may result from (1) condensate that separates during a vapor release or (2) liquid streams that accompany a vapor release. It is suggested that the volume occupied by the liquid be based on a release lasting 20-30 minutes. Any accumulation of liquid retained from a prior release (pressure relief valves or other sources) must be added to the liquid indicated in Items 1 and 2 above to determine the available vapor disengaging space. However, for situations where the knock-out drum is used to contain large liquid dumps from pressure relief valves on other sources where there is not significant flashing and the liquid can be removed promptly, it would not usually be necessary to consider these volumes relative to vapor disengaging.

The economics of vessel design should be considered when selecting a drum size and may influence the choice between a horizontal and a vertical drum. When large liquid storage is desired and the vapor flow is high, a horizontal drum is often more economical. Split entry or exit decreases the size of the drum for large flows.

As a rule drum diameters over 3.3 meters should apply split flow arrangements for best economics. Horizontal and vertical knock-out drums are available in many designs, the main differences consisting in how the path of the vapor is directed. The various designs include the following:

- 1) A horizontal drum with the vapor entering one end of the vessel and exiting at the top of the opposite end (no internal baffling).
- 2) A Vertical drum with the vapor inlet nozzle on a diameter of the vessel and the outlet nozzle at the top of the vessel's vertical axis. The inlet stream should be baffled to direct the flow downward.
- 3) A vertical vessel with a tangential nozzle.
- 4) A horizontal drum with the vapor entering at each end on the horizontal axis and a center outlet.
- 5) A horizontal drum with the vapor entering in the center and exiting at each end on the horizontal axis.
- 6) A combination of a vertical drum in the base of the flare stack and a horizontal drum upstream to remove the bulk of the liquid entrained in the vapor. This combination permits the use of larger values for the numerical constant in the velocity equation.

The following sample calculations have been limited to the simplest of the designs, items 1 and 2. The calculations for Items 4 and 5 would be similar, with one half the flow rate determining one half the vessel length.

The normal calculations would be used for Item 3 and will not be duplicated here.

Assume the following conditions: A single contingency results in the flow of 25.2 kilograms per second of a fluid with a liquid density of 496.6 kilograms per cubic meter and a vapor density of 2.9 kilograms per cubic meter, both at flowing conditions. The pressure is 13.8 kilopascals gage, and the temperature is 149°C. The viscosity of the vapor 0.01 centipoise.

Also the fluid equilibrium results in 3.9 kilograms per second of liquid and 21.3 kilograms per second of vapor.

In addition, 1.89 cubic meters of storage for miscellaneous drainings from the units is desired.

The schematic in Fig. 3 applies. The droplet size selected as allowable is 300 micrometers in diameter.

The vapor rate is determined as follows:

$$\text{Vapor rate} = \frac{21.3 \text{ kilograms per second}}{2.9 \text{ kilograms per cubic meter}} = 7.34 \text{ cubic meters per second}$$

The drag coefficient, C, is determined from Fig. 2 as follows:

$$C(Re)^2 = \frac{0.13 \times 10^8 (2.9)(300 \times 10^{-6})^3 (496.6-2.9)}{(0.01)^2} = 5025$$

From Fig. 2, C=1.3

The dropout velocity, u_d is calculated as follows:

$$U_d = 1.15 [(9.8)(300 \times 10^{-6})(496.6-2.9)]^{0.5} (2.9)(1.3) = 0.71 \text{ meters per second}$$

Assume a horizontal vessel with an inside diameter, d_i and a cylindrical length, L. This gives the following total cross-sectional area:

$$A_t = \frac{1}{4} (d_i)^2 \tag{Eq. B.2}$$

Liquid holdup for 30 minutes release from the single contingency, in addition to the slop and drain volume, is desired. The volume in the heads is neglected for simplicity. The liquid holdup required is therefore calculated as follows:

- 1) The slop and drain volume of 1.89 cubic meters will occupy a bottom segment as follows:

$$A_{L1} = (1.89 \text{ cubic meters}) \frac{1}{L} \text{ square meters}$$

- 2) A total of 3.9 kilograms per second of condensed liquids with a density of 496.6 kilograms per cubic meter accumulated for 30 minutes will occupy a cross-sectional segment (see above) as follows:

$$A_{L2} = \frac{3.9 \text{ kilograms per second}}{496.6 \text{ kilograms per cubic meter}} \times (60 \text{ seconds per minute}) (30 \text{ minutes}) \frac{1}{L} \text{ square meters}$$

The cross-sectional area remaining for the vapor flow is as follows:

$$A_v = A_t - (A_{L1} + A_{L2}) \tag{Eq. B.3}$$

The vertical depths of the liquid and vapor spaces are determined using standard geometry, (see Appendix C), where h_{L1} = depth of slops and drains, $h_{L1} + h_{L2}$ = depth of all liquid accumulation, and h_v = remaining vertical space for the vapor flow.

The total drum diameter is calculated as follows:

$$d_i = h_{L1} + h_{L2} + h_v \tag{Eq. B.4}$$

The adequacy of the vapor space is verified as follows: The vertical drop available for liquid dropout is equal to h_v . The liquid dropout time is determined as follows:

$$t = \frac{h_v \text{ centimeters}^2}{100 \text{ centimeter}^2 \text{ per meter}} \div \frac{1}{u_d \text{ meters per second}} \text{ seconds}$$

The velocity of the vapor, based on one vapor pass, is determined as follows:

$$U_v = \frac{7.34 \text{ cubic meters per second}}{1 \text{ vapor pass}} \div \frac{1}{A_v \text{ square meters}} \text{ meters per second}$$

The drum length required is determined as follows:

$$L_{min} = (U_v \text{ meters per second})(t \text{ seconds}) \times (1 \text{ vapor pass}) \text{ meters}$$

L_{min} must be less than or equal to the above assumed cylindrical drum length, L ; otherwise the calculation must be repeated with a newly assumed cylindrical drum length.

Table 3 summarizes, the calculations above for horizontal drums with various inside diameters to determine the most economical drum size. Drum diameters in 15 centimeter increments are assumed, in accordance with standard head sizes.

TABLE 3 - OPTIMIZING THE SIZE OF HORIZONTAL KNOCK-OUT DRUM (SI UNITS)

Trial No.	Assumed Drum Inside Diameter d_i (Meters)	Assumed Drum Cylindrical Length, L (Meters)	Cross-Sectional Area (Square Meters)				Vertical Depth Of Liquid And Vapor Spaces (Centimeters)				Liquid Dropout Time, q (seconds)	Vapor Velocity, u_v (Meters) per (Second)	Required Drum Lenth. L_{min} (Meters)
			A_1	A_{L1}	A_{L2}	A_v	h_{L1}	$h_{L1} + h_{L2}$	h_v	d_i			
1	2.44	5.79	4.67	0.33	2.45	1.90	30	140	104	244	1.45	3.9	5.6
2	2.29	6.25	4.10	0.30	2.27	1.53	29	137	91	229	1.28	4.8	6.2
3	2.13	6.86	3.57	0.28	2.07	1.23	28	133	81	213	1.13	6.0	6.7
4	1.98	7.62	3.08	0.25	1.86	0.98	27	128	70	198	0.98	7.0	7.4

Note:

The data in this table are in accordance with the example given in text.

The following conclusions can be drawn from this table:

- (1) All of the drum size above would fulfill the design requirements.
- 2) The most suitable drum size should be selected according to the design pressure, material requirements, the corrosion allowance, and layout, transportation, and other considerations.
- 3) The choice of two-pass flow, as shown in Figure 4, is optional.

Now consider a vertical vessel. The vapor velocity is equal to the dropout velocity which is 0.71 meters per second. The required cross-sectional area of the drum is determined as follows:

$$\text{Cross sectional area} = \frac{7.34 \text{ cubicmeterpersecond}}{0.71 \text{ meterpersecond}} = 10.3 \text{ squaremeters}$$

The drum diameter is determined as follows:

$$\text{Diameter} = \sqrt{\frac{q}{10.3 \text{ squaremeters}}} = 3.6 \text{ meters}$$

Thus, a vertical drum is not a logical choice for the example given, unless layout considerations dictate differently.

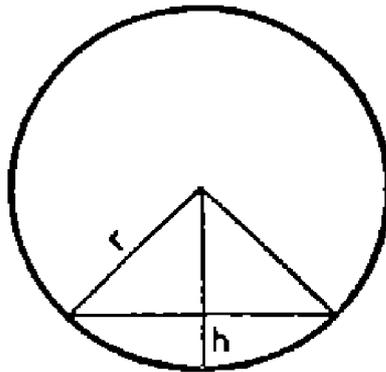
B.2 Details

- 1) If the knock-out drum would become disproportionally large, adoption of the vane type knock-out drum shall be considered.
- 2) The 20-30 minutes residence time is based on the release of maximum liquid quantity for the liquid space in the knock-out drum between high level alarm and minimum pump-out level.
- 3) The pump installed to empty the drum shall be sized to do so in two hours.
- 4) The header leading to the knock-out drum should be sloped towards it. The header from the drum to the flare stack should slope continuously back to the drum.

**APPENDIX C
DETERMINATION OF LIQUID LEVEL IN A HORIZONTAL VESSEL**

One way the liquid depth in a horizontal cylindrical vessel can be calculated is the following (volume due to heads is neglected for simplicity):

Liquid volume = (Segment area) (Vessel length)



The segment area is given by:

$$A = r^2 \cdot \cos^{-1} \left(\frac{r-h}{r} \right) - (r-h) \sqrt{2rh - h^2} \quad \text{(Eq. C.1)}$$

r and h must have similar units. Obviously the arc cosine term must be calculated in radians.

It is worthwhile to note that this equation is applicable even if h is greater than r, i.e., the vessel is more than half full.

**APPENDIX D
SAMPLE CALCULATION FOR SIZING A FLARE STACK**

D.1 General

This Appendix presents an example for sizing a flare stack based on the effect of radiation.

The effect of dispersion if the flame is extinguished is not analysed.

D.2 Basic Data:

Hydrocarbon vapor flow rate	: 12.6 kg/s
Average molecular mass of vapor	: 46.1
Flowing temperature	: 422 K
Heat of combustion	: 50,000 kJ/kg
Ratio of specific heats	: 1.1
Flowing pressure at flare tip	: 101.3 kPa (absolute)
Design wind velocity	: 8.9 m/s

D.3 Calculation of Flare Diameter

For Mach= 0.2 the flare diameter is calculated as follows:

$$Mach = (11.61) (10^{-2}) \frac{q_v}{\rho_f d_f^2} \sqrt{\frac{q}{T_f}} = k M$$

$$0.2 = (11.61) (10^{-2}) \frac{12.6}{101.3 d_f^2} \sqrt{422} = (1.1) (46.1)$$

$$d = 0.46m$$

D.4 Calculation of Flame Length

The heat liberated Φ in kilowatts, is calculated as follows:

$$\Phi = (12.6)(50000) = 6.3 \times 10^5 kW$$

From Fig. 5, the flame length, L_f is 52 meters.

D.5 Calculation of Flame Distortion Caused by Wind Velocity

The vapor flow rate is determined as follows:

$$Flow = (12.6) (22.4/46.1) (422/273) = 9.46 \text{ actual } m^3/s$$

The flame distortion caused by wind velocity is calculated as follows:

$$U_\infty/U_j = \text{Wind velocity}/\text{Flare tip velocity}$$

The flare tip exit velocity, U_j , may be determined as follows:

$$U_j = Flow / (\pi d^2/4)$$

$$U_j = 9.46 / [\pi(0.46)^2/4]$$

$$= 56.9 \text{ m/s}$$

$$U_{\infty} / U_j = 8.9 / 56.9 = 0.156$$

From Fig. 6:

$$\Sigma (\Delta y/Lf) = 0.35$$

$$\Sigma (\Delta x/Lf) = 0.85$$

$$\Sigma \Delta y = (0.35)(52) = 18.2\text{m}$$

$$\Sigma \Delta x = (0.85)(52) = 44.2\text{m}$$

D.6 Calculation of required flare stack height (for dimensional references see Fig. 9).

The design basis is as follows:

Fraction of heat radiated, F, is 0.3.

Maximum allowable radiation, Ψ , at 45.7 meters from the flare stack is 6.3 kW/m^2 .

Assume $\tau = 1.0$, then:

$$S = \frac{p}{\sqrt[4]{F''} = 4^1}$$

$$= (0.3)(6.3 \times 10^5) / 4(3.14)(6.3)$$

$$= 48.9 \text{ m}$$

$$H' = H + 1/2 \Delta y$$

$$R' = R - 1/2 X$$

$$R' = 45.7 - 1/2 (44.2)$$

$$= 23.7 \text{ m}$$

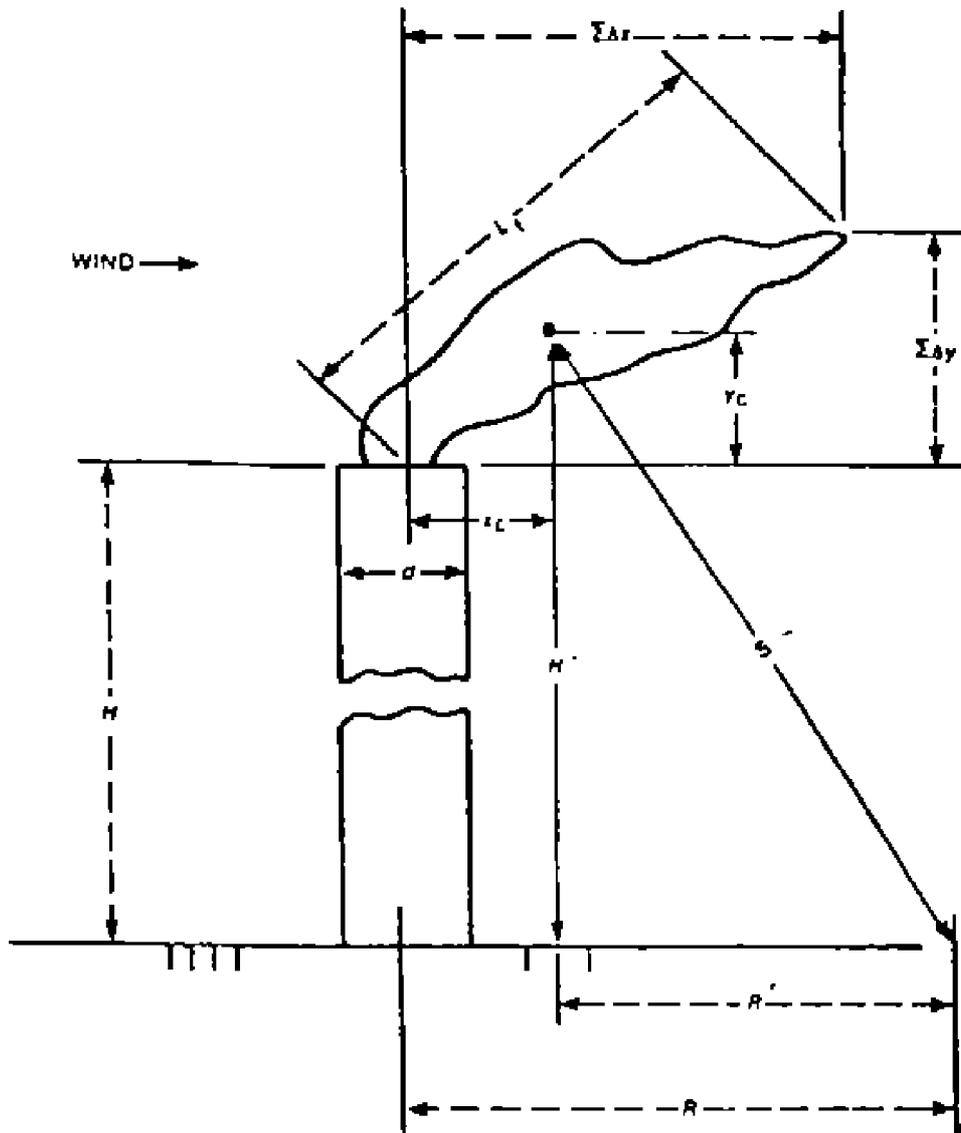
$$S^2 = R'^2 + H'^2$$

$$48.9^2 = 23.7^2 + H'^2$$

$$H' = 42.8 \text{ m}$$

$$H = 42.8 - 1/2(18.2)$$

$$H = 33.7 \text{ m}$$



DIMENSIONAL REFERENCES FOR SIZING A FLARE STACK

Fig. 9