# FLARE GAS MEASUREMENT

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## 1. INTRODUCTION

When any chemical process takes place there are waste products produced. The waste gas has to be disposed of and providing that it is not too noxious is allowed to disperse into the atmosphere via a stack or chimney. In the case of hydrocarbon gases they are usually burnt off as a "flare". It has become essential that these waste gases are metered for a variety of reasons:-

a. To obtain a mass balance to obtain the efficiency of the process.

b. To evaluate process and control the quantity of wasted energy.

c. To control emission on the grounds of environmental considerations.

The different reasons for measurement tend to a require different emphasis on accuracy. For example, in a refinary or petrochemical works, "repeatability" is more important so that optimum plant efficiency can be maintained by trend recording. An offshore platform however requires "basic accuracy" as primary importance because total volumes of energy have to be accounted for as they disappear "up the stack".

As will be described, the conditions for flow measurement in flare stacks is almost the worst possible. Gas flow measurement presents problems, but when flare conditions such as high liquid/particle content and large flowranges are imposed on the measurement, then the design of a flowmeter to adequately cope and give reasonable results is very difficult.

## 2. FLARE STACK MEASUREMENT CONDITIONS

The conditions encountered in flare stack metering are as follows:-

a. Extreme flows - from very high to very low, typically from velocities of 0.5 m/s up to 60 m/s, that is over at least 100:1 in range.

b. Wide temperature ranges, as the plant can handle both cryogenic and high temperature processes. A recent application required a range of -90 deg c up to +150 deg c.

c. The majority of gases contain either liquids or particles, typically carbon, sulphur, tar, condensate, and hydrogen sulphide which can contaminate the meter.

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d. Varying chemical composition, which makes chemical compatability of metering materials essential, particularly as many of the products are dangerous. Almost invariably the metals used to have to conform to NACE standards.

e. Density changes are wide enough to require a flow measurement method that is compensated for density and is preferably a direct mass measurement system.

f. The pipe sizes are invariably "large", that is above 300 mm. The implication being that the cost of a full bore meter is likely to be high.

g. The pressure drop must be low.

These conditions tell us about the flowmeter required, it should be inert to aggressive chemicals, measure mass flow, have a wide range and if not immune to a second fluid phase should be easily serviceable.

## 3. FLARE STACK EXAMPLE

An example of a flare stack metering application on a plant involves three flares, a high pressure line, a low pressure line and a fuel gas vent. The metering is taken at the main headers with flare feeds from the various plant processes Fig 1. For the high pressure line the flow range required on mass is 10,000:1, for the low pressure line 2000:1 and the vent line 40:1. To acheive these large ranges several meters have to be used, further more they could not be conventional full bore meters, but must be either insertion or non-invasive meters to avoid excessive pressure drop. Density in the lines vary but in the worst case can change from 0.85 to 5 $kg/m^3$. All the lines are greater than 200 mm diameter. This is a rather excessive case, due to the requirement for very low through-puts when the plant is shutdown, in the form of a purge to keep the flare going up to full blow-down conditions where there is a major plant problem.

As can be seen from Fig 1 in general the flare gas is taken off separaters. Unfortunately these usuall yonly have a limited flowrange over which they are efficient. As a consequence large quantities of liquid are likely to end up travelling down the flare lines.

## 4. STANDARD FLOWMETERS FOR FLARE MEASUREMENT

In an attempt to solve the problem of flare gas measurement nearly every meter type has been tried. The two types most commonly tried were differential pressure meters and differential pressure flowmeters they have both been used in full bore and insertion form. The success has been very limited due to the small flowrange available, the blockage of pressure tappings and in the case of orifice plates excessive pressure drop. The pressure tappings, particularly in pitot type devices, are very prone to blockage as the fluid is brought to rest at the tapping position, thus there is no tendency to remove debris by fluid action. This can only be allevited by purging to keep the tappings clear. With the advent of autoranging D.P. cells the range has been improved but is still a long way from that required in flare stacks.

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Insertion turbine meters have been used to good effect but are obviously very prone to bearing damage due to particle content. The range is good for such meters but if the meter is designed for the low flow end then a blow down will "wind" the turbine of its bearings. Equally a meter designed for the higher flows will not operate at the very low flows as the drive force to overcome bearing drag will be too small. It is thus not possible to safely cascade the meters to give the very large required range. Also the meter is true velocity measuring and thus requires density compensation.

## 5. CURRENT DESIGNS

In an attempt to solve the problems of flare metering several radically different techniques have been used. These are based on heat loss effects, vortex shedding and ultrasonics.

### a. Heat Loss Meters

Heat loss meters are the most commonly used meters for flare stack measurement. For nearly 15 years they have been used with varying degrees of success. The principle is simple, if an element whose resistance changes with temperature, such as a thermistor or PRT, is heated and placed in a flowing fluid, then the heat will be convected away by the fluid. The amount of convection is related to the mass flow. Thus by for example, heating the elements and forcing them remain at constant temperature it is possible by measurement of power (current) to obtain an output proportional to flow. A typical example is shown in Fig 2. The heat losses $Q_f$ from the flow thermistor are by forced convection:

$$\text{ie.,} \quad Q_f = \frac{E^2 f}{R} = K\Delta TS\emptyset\ (R_e) \qquad - 1.$$

The reference thermistor which is out of the main flow loses heat through natural convection, thus its heat loss $Q_R$ is given by:

$$Q_R = \frac{E^2 R}{R} = K\Delta TS\emptyset\ (G_r) \qquad - 2.$$

$$\text{now Reynolds number } R_e = \frac{V.dp}{\mu} = \frac{\dot{M}d}{\mu} \qquad - 3.$$

Sub 3. in Q

$$Q_f = \frac{E^2 f}{R} = K\Delta TS\emptyset\left(\frac{\dot{M}d}{\mu}\right) \qquad - 4.$$

Where K = Thermal conductivity of the fluid
$\Delta T$ = Temperature difference between fluid and element.
S = Surface area of element
$R_e$ = Reynolds number = $Vdp/\mu$
$G_r$ = Grasholt number = $d^3\ p^2\ g\Delta T/\mu^2 T$
V = Fluid velocity
d = Thermistor diameter
$\mu$ = fluid viscosity
E = Volts
R = Resistance

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Thus we have a measured parameter $E_f$ which is proportional to $\dot{M}$. However, there is also K, $\Delta T$ and $\mu$ to take into account. This can be allenated by taking the ratio of $E_f / E_R$ which immediately removes K and $\Delta T$ but still leaves $\mu$. In practice $\mu$ does not change to drastically for flare gases.

Conceptually therefore the method looks attractive particularly as the calibration curve Fig 3, tends to enhance the low flow end allowing the detection of very low flows, but also a reasonable high flow capability. The problem is how to range the meters particularly as they are so sensitive to flow. The main method is to allow the fluid through porting by the action by of a pressure drop across the main body Fig 4. The ported fluid can then be controlled by restrictors.

Heating is carried out in one of two ways either the thermistors/PRTs are heated directly and the current to the thermistor changed as the resistance changed or a heater element is provided seperately, Fig 5, and the thermistor/PRT detects the heat convected from the heater element, which has its heating controlled by the thermistor.

The advantage of this type of instrument is both the very large range and the output is close to a direct mass flow. It should be emphasised however that the meters are insertion meters and are influenced by flow profile, Fig 6.

The two major disadvantages of heat loss meters are the coating of the elements and in the case of using porting to control the flow, blocking of the ports. If the thermistors become coated their thermal conductivity changes and hence the calibration changes. Blocking of the porting will change the calibration, or alternatively in the worst case stop the meter completely. In the case of the meter shown in Fig 5 blockage is not a problem, but this is sacrificed to range.

b. Vortex Meters

Vortex shedding meters work on the simple principle that as fluid passes around a bluff body, Fig 7, vortices are shed alternately from either side of the body. The frequency of vortex shedding is directly proportional to flow velocity over a large flowrange. This relationship is summed up in the strouhal number relationship Fig 8, where:-

Strouhal number $S = \frac{fd}{V}$

d = bluff body diameter
f = Vortex shedding frequency
V = Fluid velocity

For a linear relationship S should be a constant for as large a range as possible. The correct shape of bluff body determines the linearity of the meter. Changes in linearity are due mainly to Reynolds number, although in gas there may be small changes with compressability at high velocities. At high Reynolds numbers there can be a change in linearity due to the boundary layer on the front surface changing from laminar to turbulent.

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If the separation points are not fixed by for example sharp edges, then the value of S will change. At low Reynolds numbers changes in the separated shear layers cause non-linearities. Fig 9 shows the variation in shedding with Reynolds numbers. It will be noted that at very low numbers there is no shedding.

From the point of view of flare stacks a very useful shape is a triangular bluff body with its apex upstream. Such a shape, while it does not give the steadiness of signal and linearity of some shapes, does give a very wide range and is particualrly good at low Reynolds numbers. Typically such a design will operate down to less than 0.5 m/s on air, with no upper limit.

A major problem area with votex meters is in the detection of the vortex shedding. There are a large number of methods, but it is sensible to concentrate on the one method that has worked successfully on flare gas. In this method a beam of ultrasound is sent across the vortices to a receiver, Fig 10. The effect of a forming vortex is to totally change the pressure and hence with gas the density. This represents a changing acoustic impedance which changes the signal amptitude. The receiver thus "sees" an amplitude modulated signal whose modulation frequency is the same as the vortex shedding frequency. To protect the transducers from the fluid the sound is fired through stainless steel "slugs", Fig 11. A typical calibration curve is shown for air in Fig 12. By virtue of the design they can be considered as "inert" meters in that they have no moving parts and by careful design present only metal (stainless steel) to the fluid.

The advantages of the meter are obvious it does have a very wide flowrange, although perhaps not yet to the lowest required flowrates, it has a pulse output and totalised flow involves negligible conversion errors and it is very robust and has been shown to work under very arduous conditions. They are working in lines where the liquid content is very high.

The main disadvantages with the vortex meters are that they do not measure mass and have to be compensated and they are an insertion meter, and they still cannot reach the very low velocities required in many flare metering applications.

c. Ultrasonic Meters

Potentially ultasonic flowmeters are very attractive for flare gas measurement, because they have no moving parts, they represent an unobstructed path to the fluid with a resultant lack of pressure drop. Even with this lack of pressure drop, by careful design a "full bore" meter can be made, compared to the insertion, point velocity measurements of thermal and vortex methods.

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There are several methods using the same basic equations to perform flow measurement using ultrasonics. They rely on the fact that if a pulse of ultrasound is fired into a fluid in motion, the time taken for that pulse to travel from two points will be modified by the fluid velocity. If the sound is travelling against the fluid flow it will take longer to travel the distance than if fired in the fluid flow direction and the difference in time is proportional to the fluid velocity. Referring to Fig 13:-

the time to travel upstream $T_{12} = \frac{d}{C - V}$ - a.

the time to travel downstream $T_{21} = \frac{d}{C + V}$ - b.

where d is distance between 1 and 2, C is the velocity of sound and V the fluid velocity.

by rearranging a. and b. we obtain the equation

$$V = Gd \left( \frac{1}{T_{12}} - \frac{1}{T_{21}} \right) \qquad \text{- c.}$$

Where d is the pipe diameter and G is geometric constant. This is written this way as it is usual to design the acoustic path to be at an angle to the fluid flow, Fig 14, to allow for more convenient installation. The advantage of this method of derivation is that the velocity of sound is excluded and the meter is independant of C. This method of direct time measurement is very difficult in liquids but is feasible in gas because of the lower velocity of sound (300 m/s compared to 500 m/s) and the generally higher fluid velocities. This ensures that the measured quantities are in the range of sensible measurement. For example, the total transit time across air in a 0.5 metre duct would be approximately 2ms and the time difference would range from 5μs (at about 0.5 m/s) to 0.5 m/s (at about 150 m/s). An electronic resolution of 100 ns would thus give good answers and such a resolution is readily obtainable.

The current production meter using this principle is designed to allow for "hot tapping" or inserion of the ultrasonic transducers into an existing line. The transducers themselves are piezo crystals mounted in a stainless steel housing and protected from direct contact with process fluid. They are mounted on stems, Fig 15, that allow for insertion into the pipe, such that if the fluid such as $CO_2$ is high attentuating signal can still be obtained by bringing the transducers closer together, and ease of installation in difficult areas.

The disadvantages of this type of meter are that it measures only direct velocity and must use a densitometer or pressure and temperature correction for mass. Also the quality of received signal will be influenced by the fluid going some repeatability problems (although this is allevited by sampling). Although the meter can be classed as a full bore meter it is subject to profile changes similar to any single path ultrasonic meter, thus there are corrections for Reynolds number changes and installation effects, but these should be less than for inserion meters.

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The advantages are a wide flowrange, with the facility to measure molecular weight from velocity of sound (if temperature is known). Accuracy is dependant upon method of installation, but can be better than 5% of actual (as opposed to FSD) on velocity measurement. Also the meter is generally less dependant upon profile than inserion meters (unless a profile is performed, but who is going to do it on a flare stack).

6. SUMMARY

a. Flare measurement is one of the hardest flow problems to solve because of the large ranges, aggressive fluids and requirement for mass measurement.

b. The more standard flowmeters do not, and have not solved the problem, with the result that newer methods are being tried.

c. Thermal methods have been used the longest for this type of measurement. They have come close to solving the problems, particularly in their range and mass. However the reliability of such meters in high concentrations of liquid and particles is poor.

d. Vortex meters, particularly using ultrasonic detection, have been very successful from the view of range and reliabililty, although they as yet have only a limited experience. The two major problems are lack of direct mass measurement and being insertion meters.

e. Ultrasonic time of flight meters are again a relative new comer but are building a good track record. There are technical problems with large ranges, but these are not difficult to solve. Perhaps the overriding advantage is that they are an easily installed "full bore" meter which few other flare meters can match. They do not however measure mass directly and may have some acoustic transmission problems.

f. The table below shows a review of the various flare flowmeters:-

| TYPE | RANGE | *ACCURACY | REPEATABILTY | COMMENTS |
|---|---|---|---|---|
| DP devices | Max 10:1 | +/- 0.5% FSD on mass | +/- 0.2% FSD | For low pressure loss must be pitot tube - holes tend to be block. |
| INSERTION TURBINE | 20:1 | +/- 1% FSD on velocity | +/- 0.1% | Easily damaged by overspeeding and secondary phase. |
| THERMAL | 300:1 | +/- 2.5% FSD on mass ** | +/- 0.5% FSD | Coating of thermistors a severe problem - also porting blockage. |
| INSERTION VORTEX | at least 100:1 | +/- 1% FSD on velocity | +/- 0.5% | Needs P and T or density to make mass. |
| ULTRASONIC | 500:1 | *** +/- 5% or better over 10:1 range on velocity | +/- 1% | Can be a full bore measurement. Needs P and T or density for mass measurement. |

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* with insertion meters there is always an error, undefined due to profile and position.

** depends on the manufacturer may be as high as +/- 5% FSD.

*** over larger ranges this accuracy decreases.

## 7. REFERENCES


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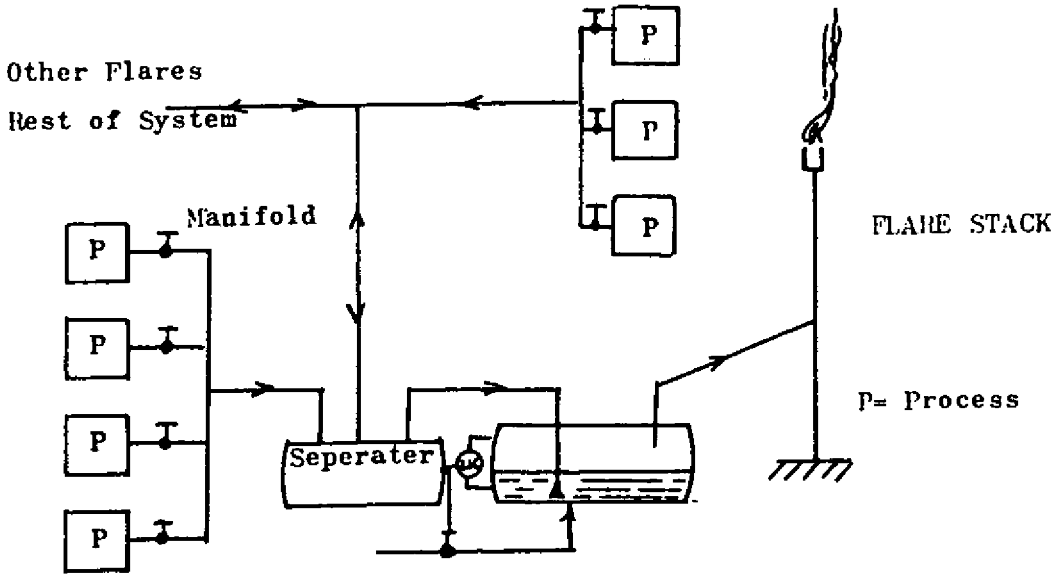


FIG .1 TYPICAL FLARE STACK SYSTEM

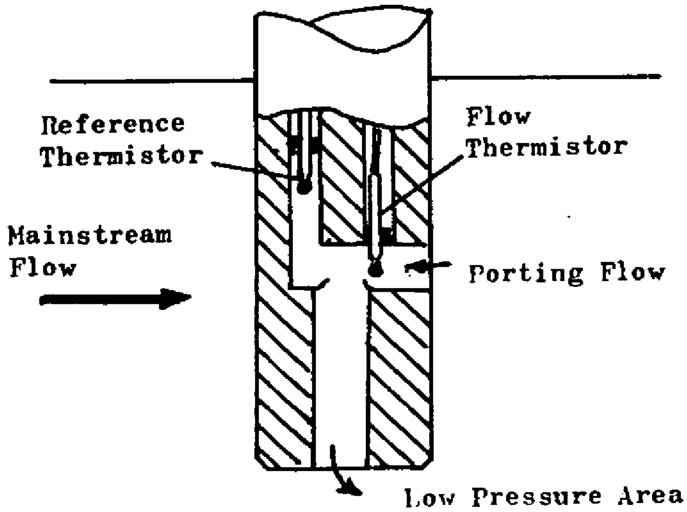


FIG. 2 TYPICAL THERMISTOR DESIGN

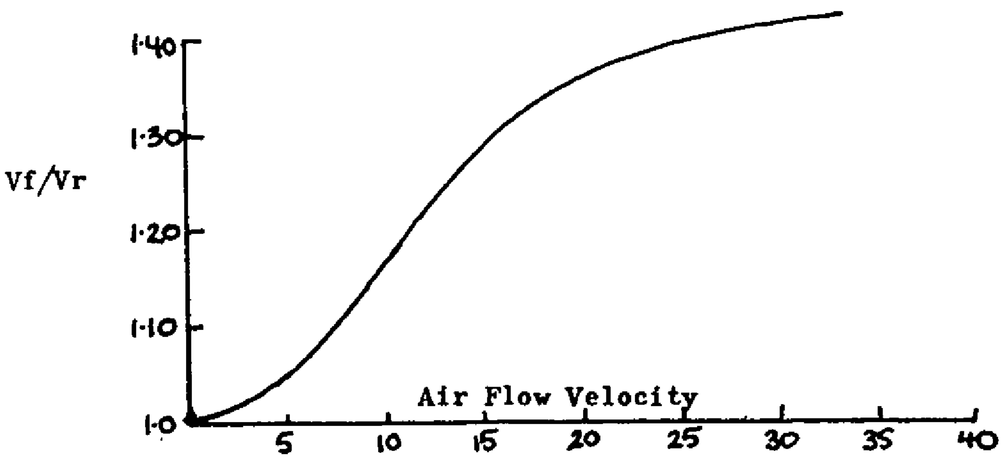


FIG.3 TYPICAL THERMAL METER AIR CALIBRATION

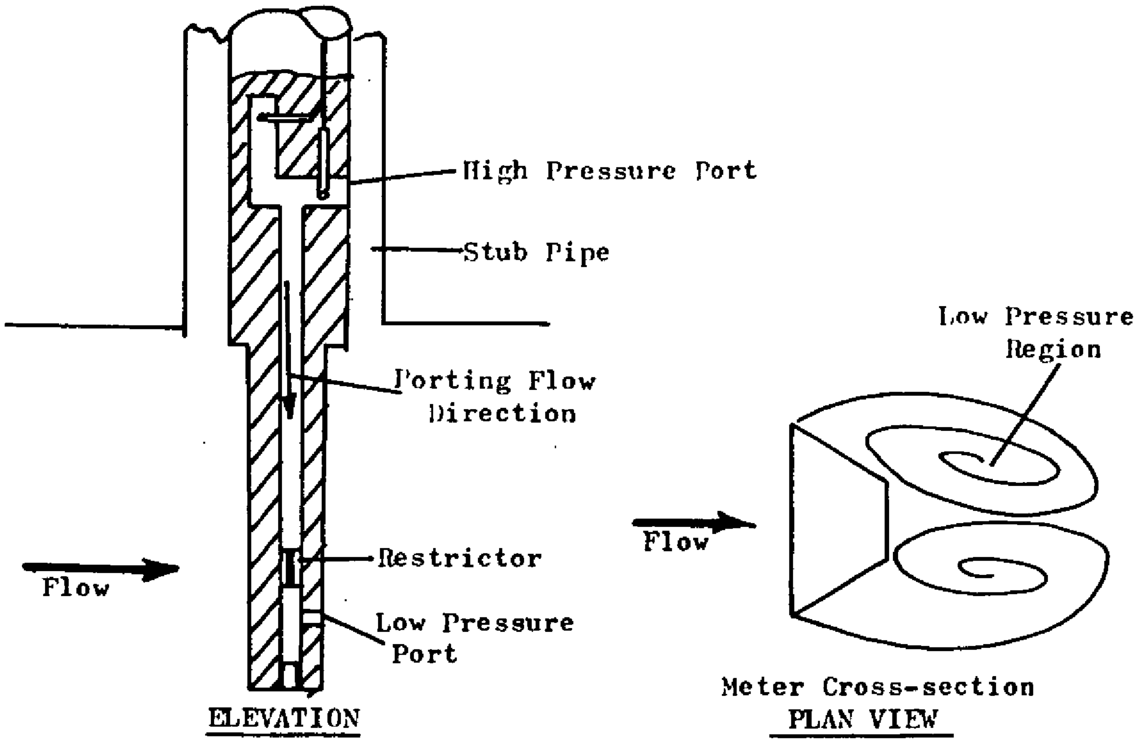


FIG.4 FLOW AROUND AND THROUGH A THERMAL FLOWMETER

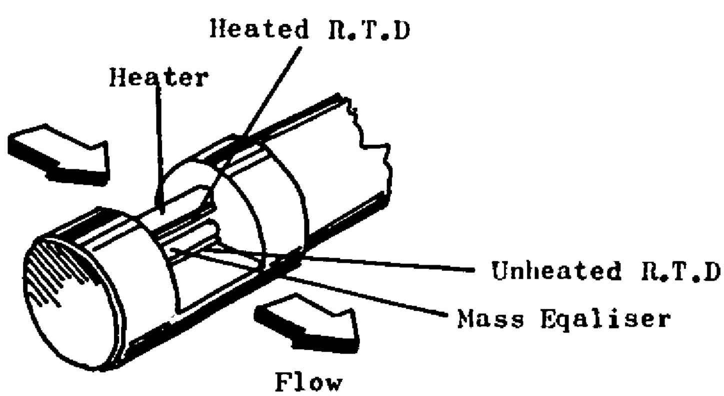


FIG.5 INDIRECTLY HEATED THERMAL METER

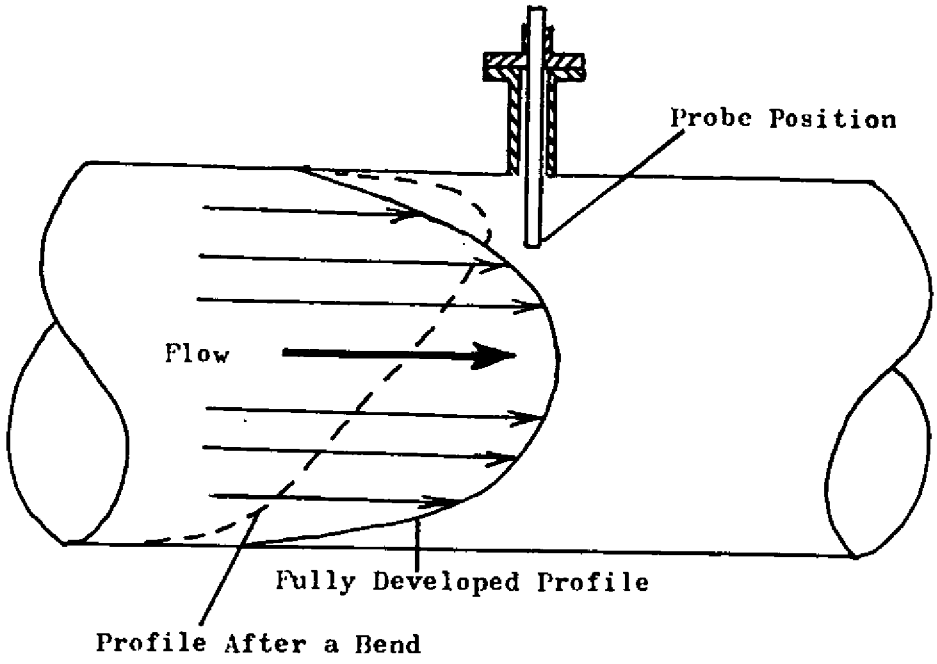


FIG.6 FLOW PROFILE EFFECT ON INSERTION TYPE METER

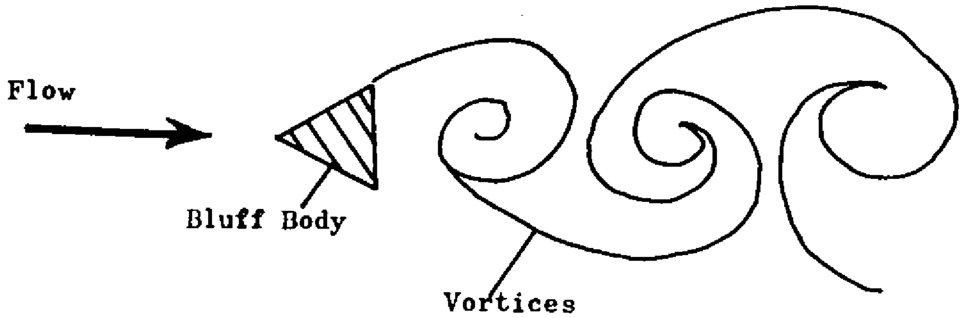


FIG.7 VORTEX SHEDDING

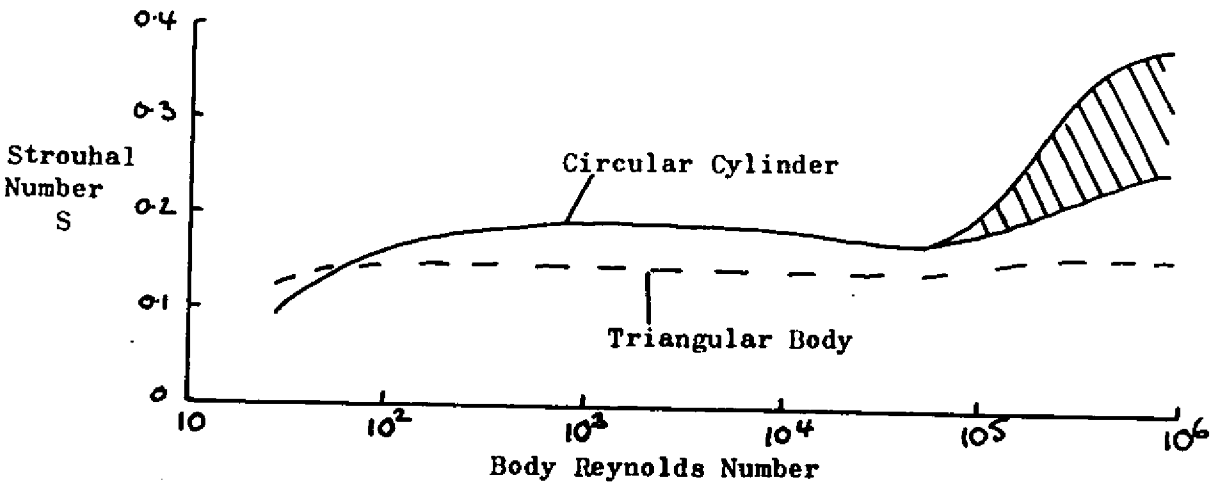


FIG.8 STROUHAL NUMBER AGAINST REYNOLDS NUMBER

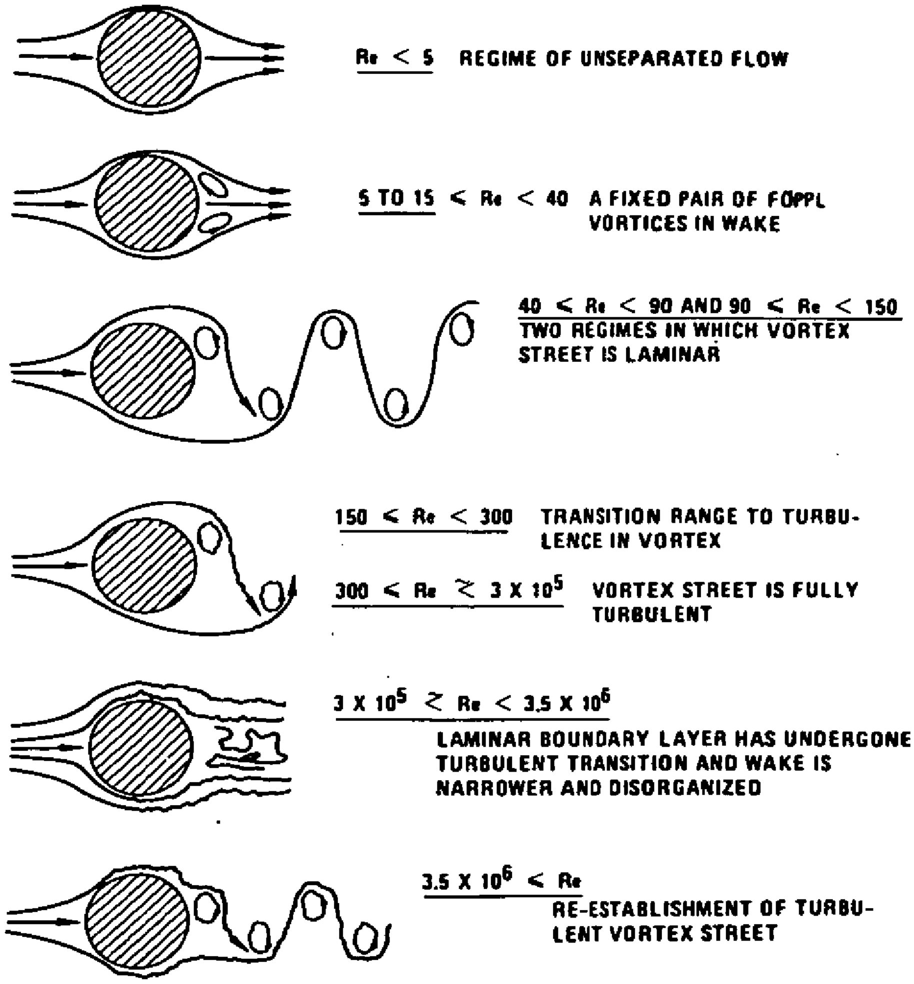


FIG.9 VARIATION OF VORTEX SHEDDING WITH REYNOLDS NUMBER

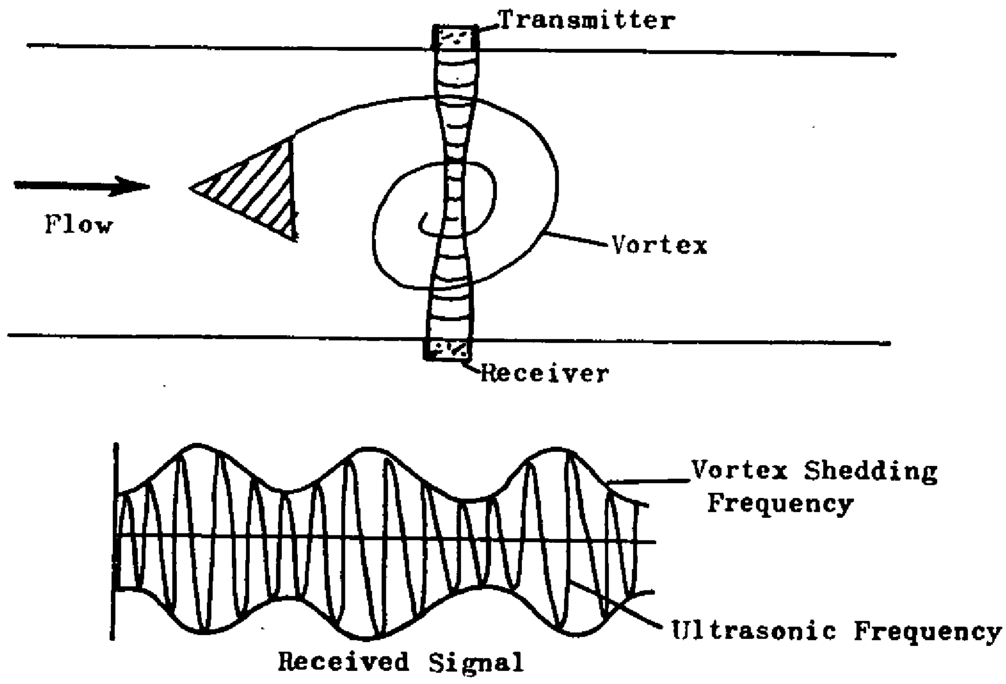


FIG.10 ULTRASONIC VORTEX DETECTION

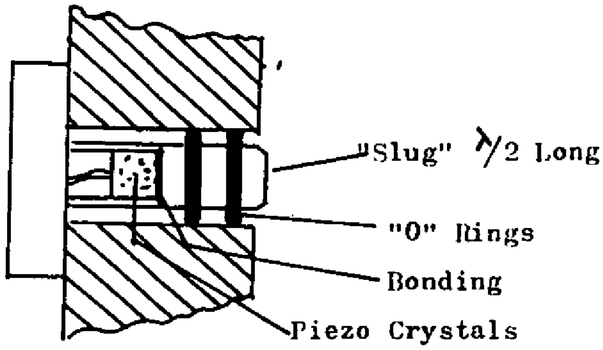


FIG.11 ULTRASONIC TRANSDUCER MOUNTINGS

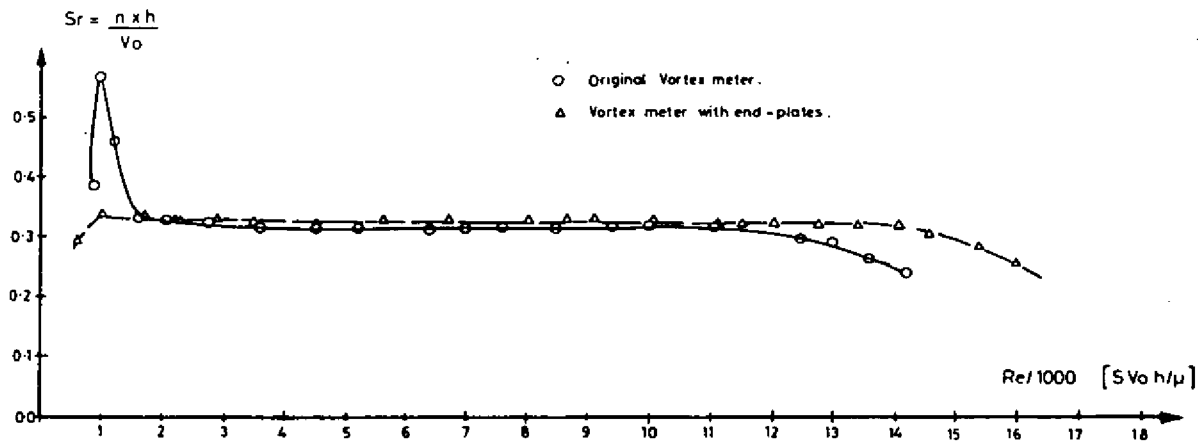


FIG.12 TYPICAL EXPERIMENTAL AIR CALIBRATION CURVES

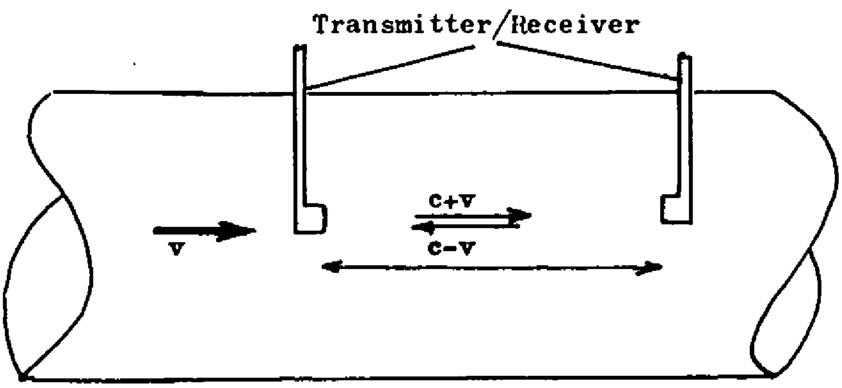


FIG.13 THEORETICAL DIAGRAM OF AN ULTRASONIC FLOWMETER

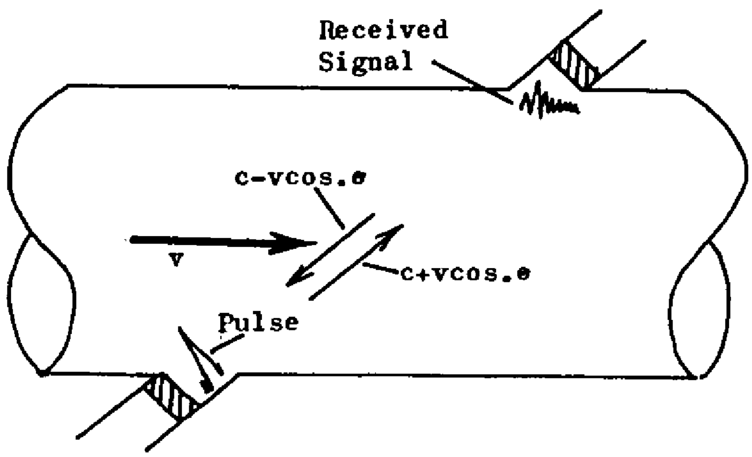


FIG.14 PRACTICAL TRANSDUCER ARRANGEMENT

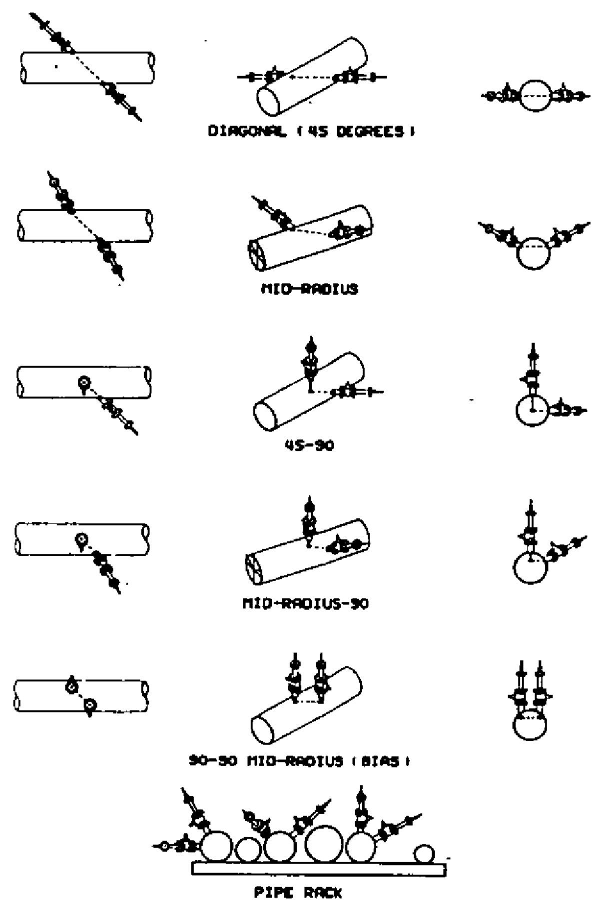


FIG.15 INSERTION ULTRASONIC ARRANGEMENTS