Importance of Flow-metering of Industrial fluids, Effluents and Waste Water for Effective Surface Water Management

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***Abstract*—In most of the urban areas of our country the water (both surface and groundwater) is heavily polluted due to domestic sewage, industrial effluents and solid wastes. The principal contaminants are acids, alkalis, carbohydrates, dyes, fats, soaps, waxes, suspended matters, oils, toxic metals and particles including radio-active materials and heated effluents. Urban population more visibly feels the adverse effect of these effluents and emissions from industrial plants. A recent survey carried-out by Central Pollution Control Board in 23-Metros in India estimates the total quantity of municipal wastes generated to be around 37058 tons per day. As the Nation continues to industrialize the urban centers will increasingly be exposed to various types of toxic and hazardous wastes. The accurate quantity of flow is a essential for future planning and management.**

Knowing the rate of flow of industrial effluents or wastewater and concentration of substances in it is necessary to find a solution of many problems in Industrial process, water supply, utilization and ultimate disposal. For purposes of establishing user charges, as well as operating treatment facilities of proportioning treatment chemicals, most plants meter the liquid. The total flow as well as the flow to individual processing areas within plant may be measured.

In our country, industrialization has already become a major cause for pollution problems. There has been a steady increase in the amount of wastewater and municipal wastes produced from urban communities and industries. Private polluters who create such risks need to treat as per the CPCB and SPCB guidelines.

There is legislation governing the discharge of noxious pollutants into the environment. In particular, for liquid pollution a difficulty in enforcing effluent standards arises when the combined load of several discharges exceeds the self-purification capacity of the receiving waters, which in turn affects the human health and aquatic life to a great extent. The increased awareness of environmental pollution has emphasized the need to measure the mass flow rate of gases, liquids and particulate concentration and the liquid into which they are dispersed. In this paper an attempt has been made to address the practical problems of metering of industrial process streams and wastewater with the help of real case studies. The importance and guidelines of proper selection of flow metering instruments for various process liquids are also discussed.

Keywords*— *flowmeter, accuracy, wastewater, selection, quantity, open-channel, pipe, sediment, silt, weirs, flumes, ultrasonic

I. INTRODUCTION

Knowing the rate of flow of industrial effluents or wastewater and concentration of substances in it is necessary to find a solution of many problems in Industrial process, water supply, utilization and ultimate disposal. For purposes of establishing user charges, as well as operating treatment facilities of proportioning treatment chemicals, most plants meter the liquid. The total flow as well as the flow to individual processing areas within plant may be measured.

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II. MASS FLOW-METERS

The most common type of mass flow meter is a split flow meter, which is typically a bypass turbine meter and measures the total steam, gas, or airflow. As the fluid enters the top chamber it passes through a calibrated orifice jets to drive a turbine assembly rotating on jewel bearings. A second set of blades on the turbine assembly rotates in a damping fluid of known density. The rotational speed of the turbine is proportional to the rate of flow. The accuracy ranges from 0.5% to 4% of full scale (Nicholas, P. Cheremisinoff, 1988).

A. Vortex Flow meters

The vortex flow meters are successfully used for 2-phase applications with air-water and gas-liquid flows up to 10% of gas content in the liquid. These mass flow meters are also called True Mass Flow Meter (TMFM) and are being used for air-water and steam-water mixtures with a maximum void fraction up to 0.5 (Class G. 2003).

Coriolis Mass Flow Meters:

In process industries like chemical, food and beverage, pharmaceutical, pulp and paper, the need to measure on-line process fluid characteristics like percent solids, liquid flow rate etc. are required. The combined abilities of a Coriolis mass flow meter to measure the mass flow and percent solid information simultaneously, provides real time control (Steve Smith & Mark Schietinger, 1995).

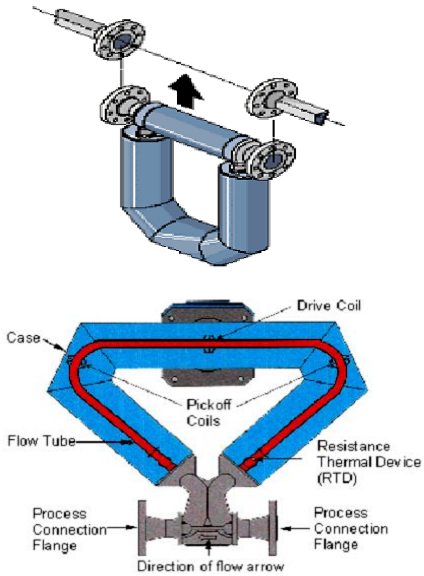

Fig.1 Coriolis Mass Flow Meter

B. Venturimeters:

A venturi will maintain its accuracy over an extremely long period of time. It is a “self cleaning and maintenance free” device. Its internal configuration, which permits smooth flow and efficient pressure recovery, eliminates erosion and resists clogging by foreign matter. While designing a venturi metering system for industrial fluid measuring applications a balancing cock or other control valve is installed down-stream so as to control fluctuating readings due to disturbed flow patterns. The venturimeter with piezometric connections are suitable for use with purge systems when used for slurries and dirty fluids. The typical accuracy ranges from 1% to 5% of full scale (Nicholas, P. Cheremisinoff, 1988).

C. Flow Tubes:

They are modified venturi tubes and most often used to meter water, sewage, air and other fluids in both municipal and industrial installations. Wide flow range is possible because of constant discharge coefficient for range of Reynolds number. These tubes do not require in-line calibration. The accuracy of the meter ranges from 1% to 5% of actual rate of flow. Venturimeter (flow tubes) with solid impurities in liquid a minimum velocity of 3m/s is required (which seems to be high for liquids) to maintain the “self-cleaning” of the meter (Azzopardi B. J. & et.al; 1989) in the pipe.
For Alum dosing and Chlorine dosing the concept of venture-meter and orifice-meter is used for dosing of chemicals in a pressured system. A needle valve and a Doser with rubber plug is normally used by taking one lead from the high pressure end and other from the low pressure side of Venturimeter or Orifice-meter.

D. Positive displacement type-
Nutating Disk Meter:

The Nutating disk meter is comprised of a movable disk mounted on a concentric sphere. The disk is contained in a working chamber with spherical sidewalls and top and bottom surfaces extend conically inward. The liquid enters the left side of the meter and strikes the disk, forcing it to rock (nutate) in a circular path without rotating about its own axis. The meter is normally used for non-corrosive liquids e.g. water, animal fats, fuel oils, vegetable oils, molasses, benzene, gasoline, coal tar distillates, fruit juices, phenol, formaldehyde, and oleum. There are several disk materials available in bronze, iron, and steel. The accuracy rating of nutating disk liquid meters is normally expressed as a percentage variation of full flow range (98%-101%). The nutating disk meters are used for liquid temperature up to 260°C (Nicholas, P. Cheremisinoff, 1988).

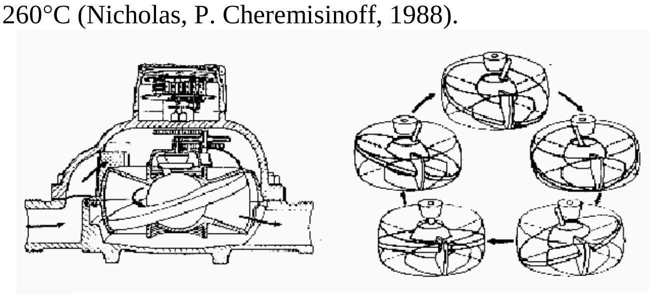

Fig.2 A Typical sketch of Nutating Disk Meter

E. Turbine flowmeters:

Turbine flow meters provide an accurate, economical method of metering a wide variety of liquid food products like milk, syrups, vegetable oils, vinegar, etc. A turbine flow meter consists of a multi bladed, free spinning, and permeable metal rotor, housed in a non-magnetic steel body. A magnetic pick-up, which contains a permanent magnet and coil, is mounted in such a way that the passage of rotor blades generates a frequency signal proportional to the flow rate. The advantage of turbine flow meter includes quick accurate response. The accuracy ranges from 0.5% to 4% of full scale (Nicholas, P. Cheremisinoff, 1988).

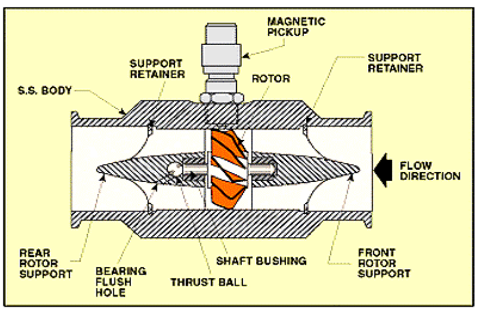

Fig.3Turbine flow meter in a Typical Industrial Installation

F. Electro-magnetic Flowmeters(MAG-METERS):

The operation of a magnetic flow meter is based on Faraday's law of electromagnetic induction. The liquid being metered must be conductive. As the fluid passes through the magnetic field, a voltage develops across the electrodes. The voltage developed is proportional to the relative velocity of the conductor (the fluid) and the magnetic field, which in turn is related to flow rate. Mag-meters (Fig.4) have been applied to metering a wide variety of conductive liquids, ranging from as low as 200µs/m. Special systems are also available which will measure the flow of liquids with threshold conductivity as low as 0.1 micro siemens per centimeter (Liptak G. Bela & Kriszta Venczel, 2001).

Fig. 4 Magnetic Flowmeter

MAG-METERS are used in a variety of process industries like chemical industries, pulp and paper industries, metal mining and refinery industries etc. They are capable of measuring acids, bases, slurries, and corrosive liquids, liquids with suspended solids, liquid metals, industrial wastes and wastewater treatment systems.

Electromagnetic flow meters when used for flow measurement for sewage sludge a special system is designed to prevent the buildup and carbonizing of sludge on the water electrodes. Such systems use self-heating principle to keep the metering body temperature at a level, which prevent sludge and grease accumulation. The typical accuracy ranges from 2% to 6% of full scale.

G Rotameter:

The Rotameter is a variable area type flow meter (Fig. 5), which can handle a very wide range of liquids like liquid metals, dense liquids and gases. It tends to be self-cleaning, which enables the meter to clean itself of some buildup of foreign materials. Liquids with fibrous materials are one of the exceptions and should not be metered with rotameters.

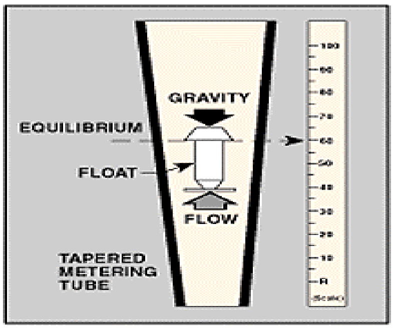

Fig. 5 Rotameter

Rotameters are relatively insensitive to viscosity variations with immunity threshold as high as 100cp. The rotameters are having accuracy range from 2% to 10 % of full-scale flow reading (Nicholas, P. Cheremisinoff, 1988).

H. Flow Metering of Non-Newtonian Liquids:

Newtonian fluids have a constant viscosity at a given temperature, for example water, oil and gases. A fluid is said to be non-Newtonian when its viscosity depends on the degree to which it has been sheared.

A Non-Newtonian Liquids does not follow Newton's Law of viscosityand follows an equation (Eq.1) of the type,

$$\tau = A\left(\frac{du}{dy}\right)^{B} + C$$

Tomato ketchup is a good example of a shear thinning non-Newtonian liquid. It can be very difficult to pour ketchup as it develops a very high viscosity when left to stand in a bottle. However, shaking the bottle will shear the fluid, reduce its viscosity and thus allow it to flow relatively easily. Other non-Newtonian fluids exhibit different characteristics such as shear thickening behaviour and visco-elasticity.

Many fluids in the *Process Sector* are non-Newtonian. Examples include slurries, chocolate, polymer solutions (e.g. wallpaper paste and food thickeners), blood, sewage, drilling fluids, china clay, emulsions and foams. There is increasing interest in the use of flowmeters with these fluids, particularly in relation to the control of continuous production processes. However, despite this increasing demand, very little is known about the performance of flowmeters in non-Newtonian liquid flows.

A review, which is done as part of a Flow Programme in 1996-99, established that Electromagnetic and Coriolis flowmeters are most commonly used with non-Newtonian fluids. The 1999-2002 Flow Programme is now funding work at the University of Liverpool in which the performance of these meters, and an ultrasonic flow meter, will be assessed in non-Newtonian liquid flows. An 80mm (3") diameter glass and stainless steel flow loop is currently being constructed at Liverpool in which the meters will be calibrated with a wide range of water-based, shear thinning polymer fluids.

The velocity and turbulence profiles entering the meters will also be measured using a laser Doppler velocimetry (LDV) system. These measurements should help to explain the behaviour of the meters under test conditions. Particular attention will be paid to the flow behaviour in the transition from laminar to turbulent flow regimes, when flow measurement errors are expected to be at their highest. Beyond 2002 the work may be extended to investigate flowmeter performance in slurry flows.

III. MEASUREMENT OF EFFLUENTS, SEWAGE IN OPEN-CHANNELS

The subject of open-channel flows assumes significance because of both its extensive uses in industrial operation and its complexity in terms of hydrodynamics. Process plant operations almost always interconnect full pipe flow arrangements with open channels and/or transitions to partial pipe flow sections.

A. Flow Measurements with Flumes and Weirs:
Flumes and weirs are primary devices for measuring rates of flow of water or sewage. These devices operate on the principle that the liquid level (H) at a given distance upstream from the weir/flume is proportional to the flow (Q) i.e. $Q \propto H^n$. 'n' is the index normally 0.5, A standard level measuring instrument (like hook-gauge or level transmitters) can be used to measure the liquid level (H) which in turn is used to compute the rate of flow. For measuring fluctuating effluent discharges special arrangements are needed to damp the level fluctuations while using the flowmeters.

B. Weirs:

Weirs are used often for measuring waste flows. They represent the simplest and often most economical approach for large flows. These weirs can be used to measure discharges accurately (2%-6% of actual flow rate) for clean coloured liquids, dirty liquids or effluents containing up to 3% solid concentration in suspension. In the use of weirs for wastewater flow measurement, care must be taken to avoid the accumulation of solids in the bottom of the box behind the weir. For measuring low flows (less than $0.03 m^3/s$) in a small to medium scale industry a V-notch weir (Fig.6) is preferred. Nomogram for estimating flow rate over 60° and 90° triangular weirs are available ($Q \propto H^{2.5}$). Rectangular weirs are of the straight or notched design. The former is called a suppressed weir without end contractions. A notched weir may have one or two end contractions ($Q \propto H^{1.5}$). Cipolletti Weir is similar to the rectangular weir except for sloping sides (One Horizontal to four vertical) of the notch. This design has the advantage of a simplified discharge formula, which is more convenient to work with than that of the rectangular weir (Ackers P. & et.al., 1980, Bajwa G. S., 1995).

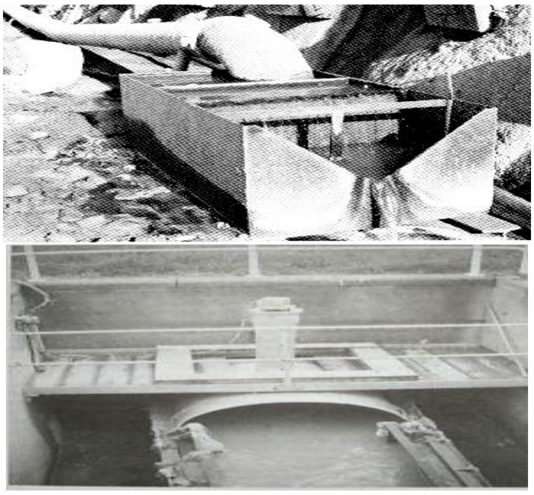

Fig. 6 Utilisation of - Notch & Magnetic Flowmeter for Liquid Effluent measurements

C. Parshall Flumes:

Parshall Flumes are normally used for measuring flows in sewers. The basic configuration consists of three parts: a converging section, a throat section, and a diverging section. Flow measurements are based on the fluid surface in the converging section. Standard charts for parshall flumes are available showing their dimensions and flow capacities. Parshall flumes are commercially available with throat width ranging from 3 in. to 40 ft. for measuring flow up to 1700 MGD. The accuracy ranges from 2% to 5% of full scale. The flow through a Parshall flume is given by,

$$Q = 2.23x10^{-5} W \left(\frac{H_a}{0.305} \right)^{1.57 W^{0.026}} \qquad (2)$$

Provided Head at d/s $H_b < 0.7 H_a$ Head at u/s and where,'W' represent the width of Parshall Flume

D. Palmer-Bowlus Flume:

In this flume a construction causes the liquid to flow at critical depth with parallel filaments. This approach is applicable to situations where space or other limitation precludes. They are used in metering stations, wastewater treatment plants and industrial waste systems. These flumes are available in one-piece constructions or in field assembled panel design. For normal range of flows the errors in discharge measurements are less than 3% of full-scale reading. The important characteristics include accuracy of measurement, low energy loss and minimum restriction to flow. Under some circumstances it may be used in pipelines also if proper consideration is given to capacity, slope and other factors. The accuracy ranges from 2% to 5% of full scale (Bajwa G. S., 1995).

Practical implications of sediment movement in weirs and flumes:
The sediments present in the wastewater or industrial effluents may sometime try to settle upstream of the weir or flume and tend to reduce the velocity in the approach channel. The errors in the discharge measurement could be computed for a given Froudes number, base height and weir coefficient (Ackers P. & et.al., 1980).

IV. OPEN FLOW NOZZLE (KENNISON NOZZLE)

This device measures discharge for liquids containing suspended solids and debris through partially filled pipes. The liquid flow to be measured emerges from a cylindrical pipe or conduit (fig. 7). All are designed to flush solids through the device without accumulations. Provisions are also made for inspection and cleaning if necessary. Due to its high accuracy (errors up to 2%–6% of actual flow), non-clogging design, and excellent head versus flow characteristics (the nozzle head is almost linear with flow i.e. Q α H, above 10% of maximum flow rate), it is well suited for measurement of raw sewage, raw sludge and digested sludge, final effluent and trade wastes (Liptak G. Bela & Kriszta Venczel, 2001).

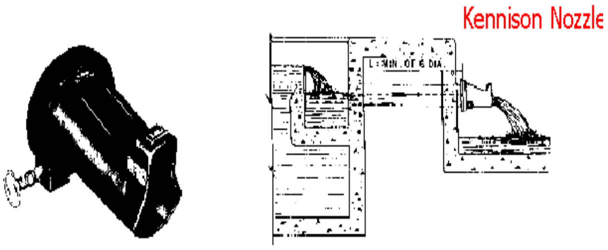

Fig. 7 A Typical sketch of Kennison Nozzle

V. ULTRASONIC FLOW MEASUREMENT

The Doppler frequency shift or time of flight method is successfully applied to measure effluent discharge and liquid level in both Pipe and Open-channel flow. The ultrasonic flow meters used for effluent measurement containing solid concentration more than 10% need to be calibrated at the field. The accuracy ranges from 2% to 6% of full scale (Nicholas, P. Cheremisinoff, 1988).

Doppler flow meters:

The Doppler flow meter relies upon the bubbles, suspended solids, or interfaces caused by turbulent eddies in the flow stream to reflect the ultrasonic energy. A sensor is mounted on the outside of the pipe to receive the signal and totalises the flow. Most manufacturers specify a lower limit of the concentration and size of solids (normally 2% suspended solids by volume) or bubbles in the liquid for reliable and accurate operation. The flow must also be fast enough, to keep the solids or bubbles in suspension, typically a minimum velocity of flow around 1.8 m/s for solids and 0.75 m/s for small bubbles are recommended (Liptak G. Bela & Kriszta Venczel, 2001).

VI. USE OF CALIBRATED TANK FOR DISCHARGE MEASUREMENTS

In some cases (Real field observations) the usage of calibrated tank (open to atmosphere) for discharge measurements of effluents particularly in small-scale industries, *where volume of treated effluents/day is relatively small and desired accuracy limits for discharge measurements are moderate (more than 8%).*

VII. CONCLUSION

The practical problems of metering industrial liquids and wastewater are highlighted. The accuracy of flowmeters in effluent measurements is greatly affected by industrial process environment (pressure, temperature etc.) and presence of foreign material in the liquid. The paper gives a brief guideline to select a suitable flowmeter (refer Table-1) to measure the effluent discharge/day of an industry and helps to compare it with the prescribed limit by the State pollution control board or regulating authority of the Country.

Flow-metering of industrial effluents for a given industrial area also provides a basis for charging, (on individual basis), where facilities like combined treatment plant for effluents and solid wastes are present.

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TABLE – 1 List of Flow Meters Used For Measurement Of Industrial Fluids & Effluents

Sl No.	Type of Flowmeter	AREA OF APPLICATION	Accuracy Range %
1	Magnetic Rotameter	Used for cleaner liquids and gases, Hazardous fluids, High pressure fluids, Opaque fluids.	1 to 10 of F.S.
2	Venturi-meter Flow tubes	Used for dirty water, containing foreign materials	1 to 5 of F.S.
3	Mass flow-meters: Split &Turbine flowmeter	It measures total flow of Steam, Gas or Air, Liquids like milk, cheese, whey, syrups, vegetable oils, vinegar etc. (also gas components & fraction in liquids)	0.5 to 4 of F.S.
4	Mass Flowmeter (Thermal type)	Gas Mass flow normally used in gas mixing system, cooling air flows, engine inlet air flows, manufacture of semi-conductors	0.4 to 4 of F.S.
5	Nutating Disk Meter	For Animal fats, fuel oil, glycol, brine, liquid sugar, oils, molasses, benzene, gasoline, nitric acids, formaldehyde, hot & corrosive liquids	1 to 6 of F.S.
6	Ultrasonic Phase shift flow meter	Suitable for wastewater, service water, lubricating oils, highly corrosive liquids, for all liquids bearing 25PPM of 30 microns or larger suspended solids or bubbles.	1 to 20 of F.S.
7	Using calibrated open tank	Clean, dirty liquids are measured after separating the suspended load by mechanical or chemical means.	5 to 15 of F.S.
8	Magnetic Flow Meters (Mag Meters)	For all types of corrosives, strong acids and bases, metal, viscous materials, pulp & paper industry, dyes, sludge, slurries, alum, Influent/ Effluent waste treatment, chemical wash, liquids with suspended solids.	2 to 6 of Actual flow
9	Palmer – Bowlus & Parshall Flume	Used in waste water treatment plants, and industrial effluent systems, severs.	2 to 5 of F.S.
10	Open Flow nozzle (Kennison nozzle)	Suitable for low flows to wide flow ranges for liquids containing suspended solid and debris for partially filled pipes, raw sewage, raw and digested sludge, final effluent, trade wastes.	2 to 6 of F.S.
11	Ultrasonic flowmeter	For suspended loads, Industrial slurries (coal, cement), two-phase liquids ,milk paint emulsion,sewage & industrial effluents, paper & pulp, mining, petroleum & refining.	2 to 6 of F.S.
12	Notches & Weirs	Suitable or liquid effluents, slurry and sludge flow. (using ultrasonic sludge switches) etc.	2 to 6 of F.S.

Note: 1. F.S. - Stands for full scale reading 2. Higher the solid Impurity in the liquid or gas the measuring error will be on higher side