An Analysis of Flow Measuring Mechanisms to Arbitrate Losses in Bends and Fittings for Analogous Operations

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ABSTRACT

Measurement, monitoring and analysis of fluid flow are important procedures in the process industry. The focus of this study was to analyse the flow measuring mechanism officiated to arbitrate shrinkages in bends and fittings owing to analogous operations. The results were computed by a flow analysis of the system based on the head loss of each respective equipment. The bends and fittings considered were the venturi meter, orifice meter, rotameter, diffuser, and right-hand bend. It was observed that the venturi meter is the most defined estimating equipment for the measurement of flow owing to its exactitude and calculable measurement. It was furthermore observed that the rotameter is the most unfavourable in contrast to venturi meter and orifice meter which has much lower head losses. With regards to installation cost, it has a lesser disadvantage compared to the orifice meter as the latter is easy to set-up and is the most economical device for flow measurement. Considering that virtually all petroleum mechanical operations reckon on flow measurement, it is compulsory to make use of highly productive devices with good veracity (70% for venturi meter) and minimal head-losses.

Keywords: Flow measurement; venturi meter, orifice meter, rotameter, head loss

Introduction

Measurement, monitoring and analysis of fluid flows are very important in the process industry[2]. Instruments used for determining flowrates of fluids are usually referred to as flowmeters[3]. We have the mechanical and pressure-based flowmeters. The former includes piston meter, rotating piston meter, variable area meter, turbine flow meter, Woftmann meter, whilst the latter category includes venturi meter, orifice plate, pilot tube, multi-hole pressure probe meter amongst others. Research investigations into fluid flow in into fluid flow in recent times have come in the domain

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measurement and data transmission4,5, instrumentation6,7, theoretical modelling3,8, computer aided modelling9,10,11 and a host of other approaches.

Different aspects of a variety of flowmeters (especially orifice meters, venturi meters and rotameters) have been studied in open literature. A study was carried out on the effect of fluid viscosity on the rotameter[7]. Theoretical models were developed to examine the effect of density, viscosity, orifice plate area and pressure on fluid flow characteristics[3]. Tukiman et al.[11] harnessed computational fluid dynamics technique in investigating fluid flow through orifice plates. The flow characteristics of multi-hole orifice meters was evaluated both numerically and experimentally[10]. A study was carried out on the effect of an abrupt change in the pipe diameter on the accuracy of venturi meters using computational fluid dynamics[9]. An analysis was carried out to investigate how the orifice to pipe diameter ratio affects fluid flow characteristics (specifically the flow field behind a thin circular square-edged orifice plate)[12]. A comparison was made to study how different orifice geometries and evaluated how they affect pressure drop using computational fluid dynamics[13]. Murugan et al[14] used harnessed artificial neural networks in doing a non-linearity error compensation for venturi flowmeters. Ifft[15] evaluated and compared the permanent pressure losses from a variety of recent flowmeter technologies. Elobeid *et al.* (2016)A study was carried out on the effect of inclination and water cut on venturi pressure drop measurements for oil-water flow

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experiments[16]. A variety of other studies on the orifice meters[17], venturi meters[17,18], rotameters[19] and bends[20,21] have been conducted in recent times. Most of these studies evaluated bends and fittings in flow-lines in a standalone perspective. Arbitrating head losses in systems with a combination of bends and fittings is unreported based on the above review.

The presence of bends and fittings on flow lines tends to have negative effect on the fluid flow in that the head losses are increased. It is important to recover flow head as quick as possible to save energy and cost[13]. For more efficient process operation, analysis to arbitrate these losses and determine the advantages and consequences of different flow measurement devices is pertinent. After a thorough search by the authors, it was observed that studies have not endeavoured to evaluate the arbitration of head loss in combinatorial apparatus consisting of and inter-related sequence of bends and fittings. This study seems quite a first of its kind in this approach. It is pertinent that this gap in knowledge be exploited as it would be invaluable to process systems engineers. The aim of this study is to analyse the flow measuring mechanism officiated to arbitrate shrinkages in bends and fittings owing to analogous operations. The results will be computed by a flow analysis of the system based on the head loss of each respective equipment. The bends and fittings to be considered in the study are the venturi meter, orifice meter, rotameter, diffuser and right-hand bend. This study comes at a time where concerted effort is being made to reduce head losses in general and those due to flow-line instrumentation.

Methodology

Experimental Setup

The order and arrangement of the bends and fittings on the flow line are represented in figure 1. The water goes into the set-up (Figure 1) through a transparent thermoplastic acrylic resin venture lilt which consists of a vertical continuously focusing section, superseded by a gorge, then by a vertically increasing deviating section. Pressure estimations that take place in the currents occur at the entrance to the meter point (A) at the passage (B) and at the outlet (C). Following a correction in the segment through a briskly splitting area and a farther estimating terminal (D), the stream heads down a sealing expanse and goes through the orifice plate meter.

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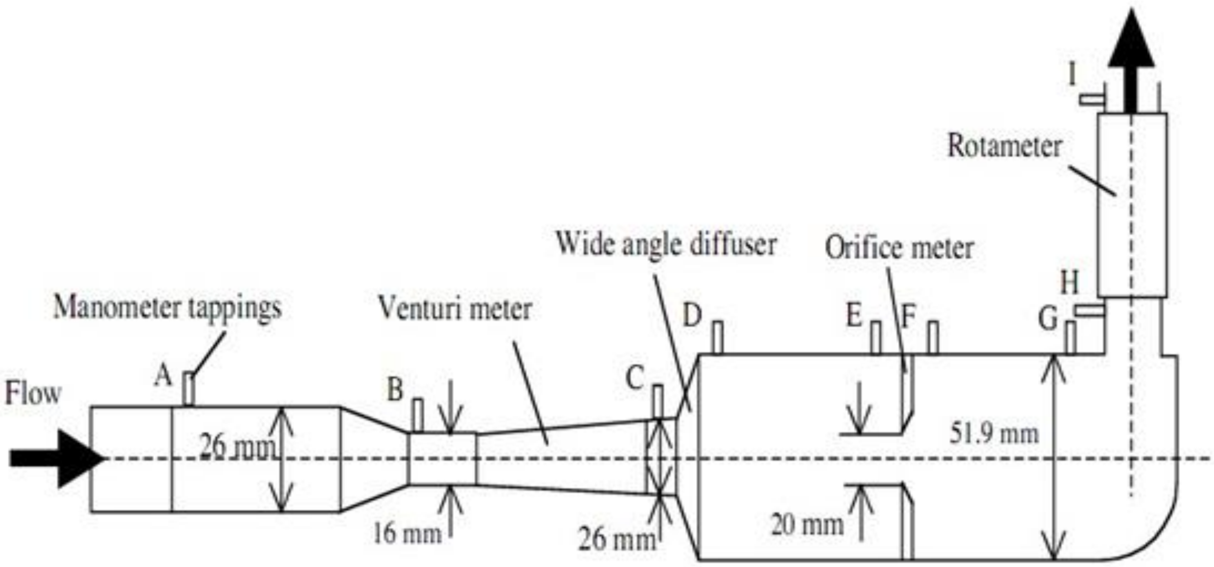

Figure 1: Flow Measuring Apparatus

This cadence is produced from a brass plate having a grip of curtailed diameter through which the liquid flows and is seated in-between two pressure ebbed Perspex rims (E) and (F). After a sealing expanse and a right-angled inflexion which is also pressure remitted (I) and (H) (so that inflexions perdition coefficient may be desired), the stream is introduced into the rotameter. This comprises of a translucent remitted tube for an estimation of the wharf, appraised from the extent on the barrier of the rotameter, is an estimate of the flowrate. The pressure decline over the rotameter is achieved from the manometer alignment (H) and (I). Succeeding the rotameter, the water rebounds by means of control nozzle to the pneumatic seat and measure vessel.

Experimental Procedure

The equipment for measuring flow was placed in position. The water injection was turned on using a switch positioned at the margin of the set-up. The nozzle was habituated until the rotameter stream was at a suitable intermediate position on its tapered tube. The stream rate was contracted through the use of a bridled nozzle till the point where no flow was detected. An array of experimental values was then appropriated from each equipment i.e., the orifice meter, rotameter, etc., and the gotten values duly noted. After obtaining the values, the water was acquiesced to spurt. While the amount of water pumped was about a mass 1kg, the time-ticker was stopped and the time value summarily recorded. The arrangement was later ebbed in position to be un-stabled by 2kg.

Analysis of head loss and inlet kinetic head

The readings from the rotameter are in centimeters while the manometric readings are in millimeters. All computations are in infinite values to limit the condition of negative values. For the venturi meter:

Discharge: $Q = 9.55 \times 10^{-4}(h_A - h_B)^{1/2}$ in m^3/s

Mass flow: $m = 0.955(h_A - h_B)$ in kg/s

Inlet kinetic head: $kh = 0.156(h_A - h_B)$ in meters

Head loss: $\Delta h_{AB} = (h_A - h_B)$ in meters

For the orifice meter;

Discharge: $Q = 9.10 \times 10^{-4}(h_E - h_F)^{1/2}$ in m^3/s

Mass flow: $m = 0.910(h_E - h_F)$ in kg/s

Inlet kinetic head: $kh = (\frac{1}{6})0.156(h_A - h_B)$ in meters

Head loss: $\Delta h_{EF} = (h_E - h_F)$ in meters

For the rotameter, the mass flow is determined from the plot of mass flow against discharge gotten from the equipment manual. And the density of water (p) was taken as 1000 kg/m^3.

Discharge: $Q = \frac{m}{p}$ in m^3/s

Head loss: $\Delta h_{HI} = (h_H - h_I)$ in meters

Inlet kinetic head: $kh = 0.156(h_H - h_I)$ in meters

For the diffuser

Inlet kinetic head: $kh = 0.156(h_C - h_D)$ in meters

Outlet kinetic head: $kh_{out} = (\frac{1}{16})kh$ in meters

Head loss: $\Delta h_{CD} = h_C + kh - kh_{out}$ in meters

For the right-angled bend

Inlet kinetic head: $kh = 0.156(h_G - h_H)$ in meters

Outlet kinetic head: $kh_{out} = (\frac{1}{16})kh$ in meters

Head loss: $\Delta h_{GH} = h_G + kh - kh_{out}$ in meters

Where kh is the kinetic head, Δh is head loss, Q is discharge and m is mass flow. The relevant units are alongside each formula. Letters A to I are referring to points marked in figure 1.

Results and Discussion

Upon performing the experiments, the readings from the venture meter, orifice meter and rotameter were tabulated and represented in table 1. Letters A to I are as indicated in figure 1.

Table 1: Readings obtained from the apparatus

S/N	A (mm)	B (mm)	C (mm)	D (mm)	E (mm)	F (mm)	G (mm)	H (mm)	I (mm)
1	185	180	120	150	157	160	165	170	100
2	190	185	125	160	165	170	175	180	110
3	195	190	135	165	170	175	180	185	120
4	200	195	140	170	175	180	185	190	130
5	205	200	150	175	182	185	190	195	140

Applying the equations in section 2.3 against the data obtained in the table (albeit converted to meters), we obtain the data presented in tables 2, 3, 4, 5 and 6 for venturi meter, orifice meter, rotameter, diffuser and right-hand bend respectively.

Table 2: Readings for the Venturi Meter

S/N	Mass flow (kg/s)	Inlet kinetic head (m)	Head loss (m)
1	0.0675	$7.80\text{x}10^{-4}$	$5\text{x}10^{-3}$
2	0.0675	$7.80\text{x}10^{-4}$	$5\text{x}10^{-3}$
3	0.0675	$7.80\text{x}10^{-4}$	$5\text{x}10^{-3}$
4	0.0675	$7.80\text{x}10^{-4}$	$5\text{x}10^{-3}$
5	0.0675	$7.80\text{x}10^{-4}$	$5\text{x}10^{-3}$

Table 3: Readings for the Orifice Meter

S/N	Mass flow (kg/s)	Inlet kinetic head (m)	Head loss (m)
1	0.0498	$1.30\text{x}10^{-4}$	0.003
2	0.0643	$1.30\text{x}10^{-4}$	0.005
3	0.0643	$1.30\text{ x}10^{-4}$	0.005
4	0.0643	$1.30\text{ x}10^{-4}$	0.005
5	0.0498	$1.30\text{ x}10^{-4}$	0.003

Table 4: Readings for the Rotameter

S/N	Mass flow (kg/s)	Inlet kinetic head (m)	Head loss (m)
1	0.225	1.092×10^{-2}	0.070
2	0.250	1.092×10^{-2}	0.070
3	0.275	1.014×10^{-2}	0.065
4	0.300	9.360×10^{-3}	0.060
5	0.325	8.580×10^{-4}	0.055

Table 5: Readings for the Diffuser

S/N	Inlet kinetic head (m)	Outlet kinetic head (m)	Head loss (m)
1	4.68×10^{-3}	2.925×10^{-4}	0.1244
2	5.46×10^{-3}	3.413×10^{-4}	0.1301
3	4.68×10^{-3}	2.925×10^{-4}	0.1394
4	4.68×10^{-3}	2.925×10^{-4}	0.1444
5	3.90×10^{-3}	2.438×10^{-4}	0.1537

Table 6: Readings for the Right-angled Bend

S/N	Inlet kinetic head (m)	Outlet kinetic head (m)	Head loss (m)
1	7.80×10^{-4}	4.875×10^{-5}	0.166
2	7.80×10^{-4}	4.875×10^{-5}	0.176
3	7.80×10^{-4}	4.875×10^{-5}	0.181
4	7.80×10^{-4}	4.875×10^{-5}	0.186
5	7.80×10^{-4}	4.875×10^{-5}	0.191

Evaluating mass flows against inlet kinetic head

The linear representation of mass flow rate of the venturi meter, orifice meter and rotameter against inlet kinetic head is shown in figure 2. It illustrates that the interrelation of the rate of flow of the venturi meter can be conveniently curtailed because the fluctuation can be clearly anticipated. The rotameter's flow rate value can be curtailed although not as conveniently as the venturi meter whilst that of the orifice meter is least basically bridled.

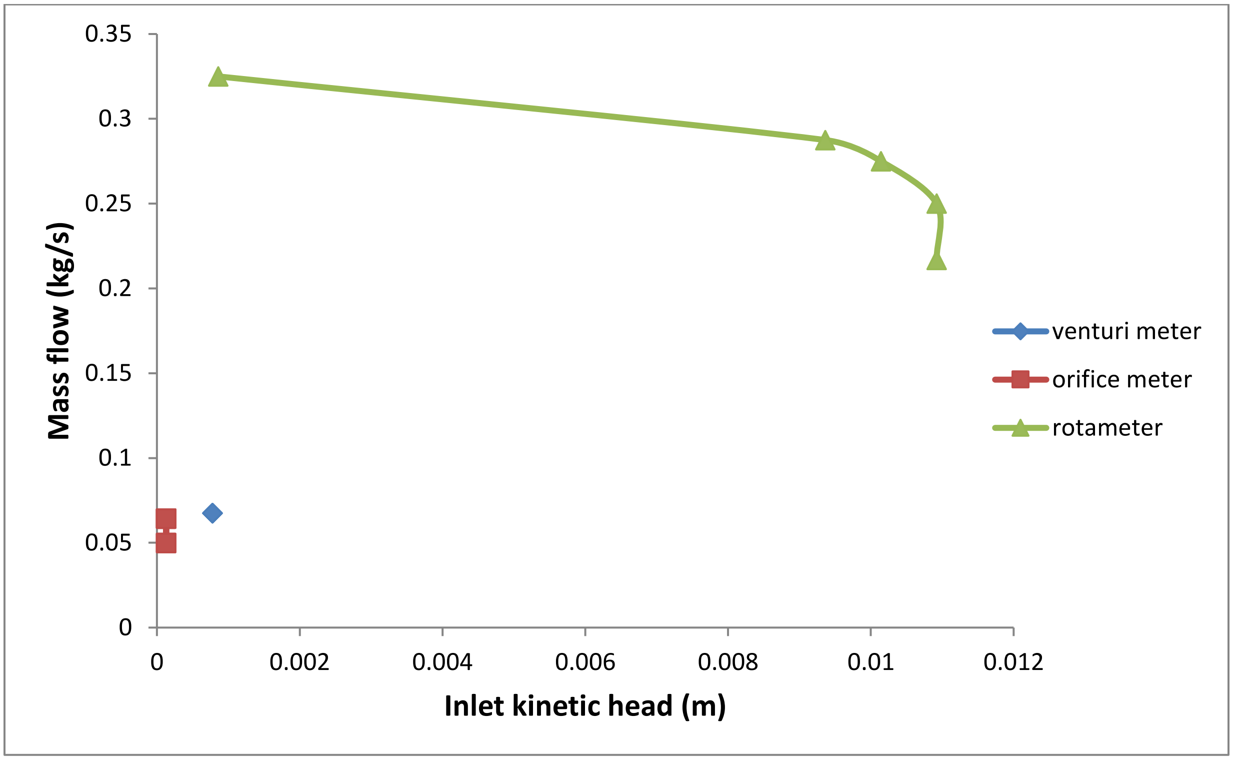

Figure 2: The plot of Mass flow against Inlet Kinetic Head for Venturi meter, Orifice meter and Rotameter

Furthermore, it can be observed from the plot in Figure 2 that limited variables exists in exactness of discharge measurements when comparing the orifice meter, rotameter, and the venturi meter. They are completely reliant on the same fundamentals. Discharge co-adjuvants and the rotameter appraisals are seriously dependent on the procedure by which the flow creates a Verna-contracta or factual nozzle of smaller sample area other than that of the constricting tube. This consequence is trivially cramped where a contained contraction occurs in a venturi meter but is symbolic in the orifice meter. The release coefficient of the orifice meter is also related to the actual position of the manometric tappings (E) and (F).

In contemplation of retaining the apparatus as compressed as feasible, the proportion twinge equipment in the vicinity of the Orifice meter was subjected to a reduction process. Therefore, some imprecision in the settled value of its release coefficients was expected. The difference in head loss betwixt the venturi meter and the orifice meter was significant. The orifice meter is easier to produce and use, for it is approximately easy to create a convenient orifice plate and embed it between two conduit rims which have been conveniently pressure tapped for the goal. Contrary to the characteristics of the orifice meter, the venturi meter is quite difficult to produce and convoluted to benefit the existing flow arrangement. However, the minimal head loss connected with the contained expansion taking place in the venturi meter gives it a clear dominance and advantage in its utilisation where the capacity to subdue flow losses may be minimal.

Evaluating head losses against inlet kinetic head

Rotameter and alternative instruments for flow measuring which reckons on the movement of floats in receded tubes may be chosen amidst an extensive range of conditions. They are considered to be proportionate to the Venturi meter from the viewpoint of head loss, although since the dimension of discharge is minimal, the ease of analysing the equipment may well recompense for the considerably higher head losses associated with its use. The head losses associated with the wide-angled diffuser and the right-angled bend are not abnormal. The head loss of the diffuser could be attenuated if the entire extension angle of approximately 50 degrees were curtailed to about 10 degrees. The right-angled bend loss can be considerably limited if the medium by which the water passes through was fabricated in the curvature of a circle having an extensive radius in contrast to the conduit bore encompassing the fluid. Flow arrangements that experience large losses are associated with unconstrained segment of the stream. The system should always be scrutinised for increases in outlined segments and anomalies in the direction of the flow as these aspects of the system are most susceptible with regards to head loss.

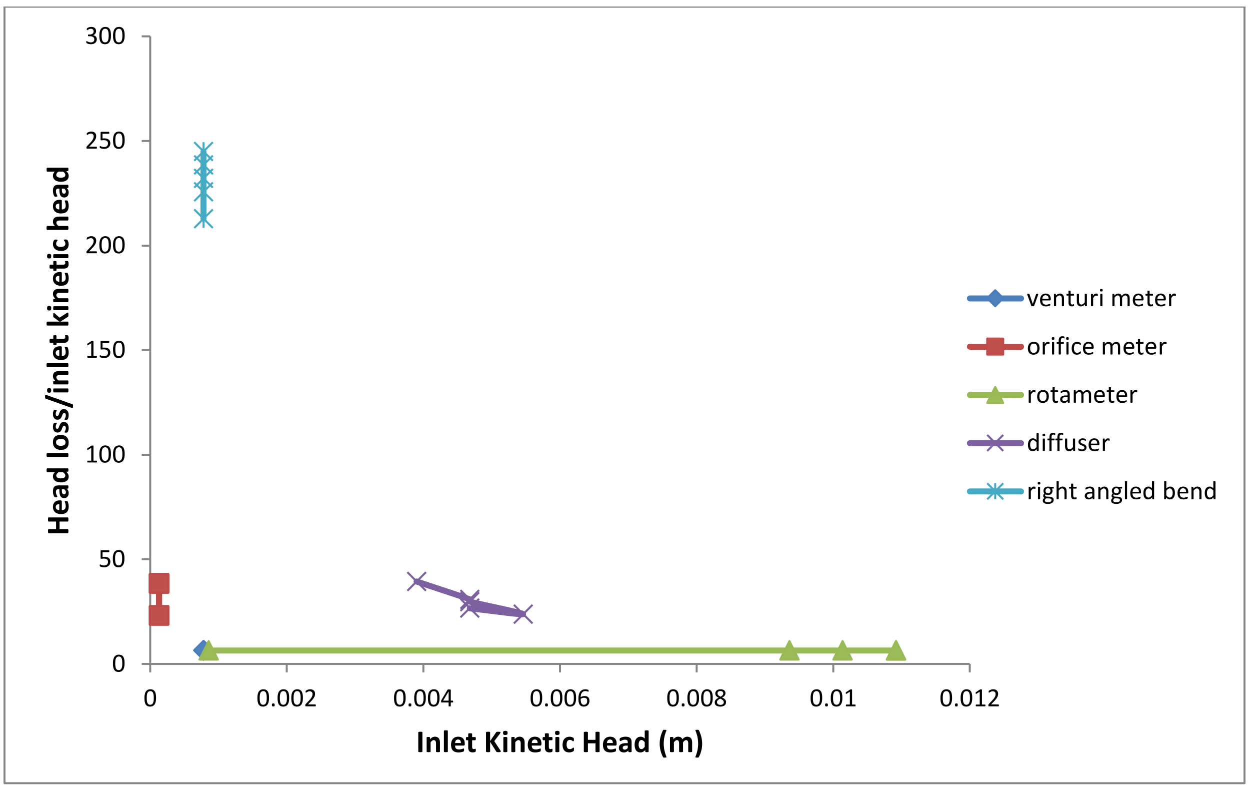

Figure 3: The plot of Head loss/Inlet Kinetic head against Inlet Kinetic head of the Venturi meter, Orifice meter, Rotameter, Diffuser and Wide angled bend

Figure 3 illustrates that the rotameter bids absolute values through the regulation of a float, this makes its regulation very apparent. Although owing to the rotameter having the topmost head-loss, its values are not entirely specific values because readings are interior 1% for the orifice and venturi meters, and they are around a value of 5% for the rotameter. The constant of setting-up, on the integral of the orifice is an immense edge although from the second outline (figure 3), a consistent interrelation for the rotameter and venturi meter and a moderate dynamic relation for the orifice meter is noticed. The more immense the head-loss, the minimal the veracity and the lesser the head-loss, the higher the veracity. This is the reason why the rotameter is the most unfavourable in contrast to venturi meter and orifice meter which has much lower head losses.

Conclusion

The analysis of the flow measuring mechanism officiated to arbitrate shrinkages in bends and fittings owing to analogous operations were conducted in this study. The results were estimated by flow analysis of the system which involved determining the head loss of respective equipment on the flow line. It was observed that the venturi meter was the most defined estimating equipment for the measurement of flow owing to its exactitude and calculable measurement. With regards to setting up and cost, it has a minimal detriment when in contrast with the orifice meter, which is quite easy to set-up and the most economical device for flow measurement. The orifice meter however does not provide an exact reading when compared to the venturi meter. It was furthermore observed that the rotameter is the most unfavourable in contrast to venturi meter and orifice meter which has much lower head losses. It is the duty of an engineer to operate with specific and defined devices in contemplation of yielding adequate and high-quality values. Consequently, the venturi meter is the most preferred flow measuring equipment for Petroleum Engineering whilst regulating reservoir flows. Considering that most process systems operations involve flow measurement, it is compulsory to make use of highly productive devices with good veracity and minimal head-losses. Haven noticed that the venturi meter is the most exact, it should be used in the measurement of flow (and it has a veracity of 70%). Appropriate conservation of the venturi meter is also required in order to make sure the venturi meter has an extensive life period and functions as efficiently as achievable.