TECHNICAL PUBLICATION

Title: **Permanent Wellbore Monitoring – Components of the Bubble Tube System & System Features**

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ABSTRACT

Using the PROMORE Bubble Tube System (PBTS) operators can reliably monitor high temperature wellbore environments. The industry utilizes this method of monitoring downhole pressures when wellbore temperatures exceed 150^0C , typically beyond the capability of downhole electronic-based systems or are in excess of the temperature capability of downhole electronics-free systems. This technical publication illustrates the advantages, limitations, and the main components of the PBTS.

TECHNOLOGY OVERVIEW

PBTS systems are utilized in thermal fields, which have excessively high geothermal gradients and in fields undergoing tertiary thermal recovery operations. A gas contained within a capillary tube transmits the bottom hole pressure to surface, which is measured by a pressure transmitter. There are limitations associated with this measurement method and precautions, which must be taken to ensure success. A system properly designed for wellbore fluids and varying pressures can provide reliable bottom hole pressure data.

The technology is well suited for producing environments where operators need the benefits of reliable permanently measured pressure data to proactively assess reservoir performance, optimize artificial lift systems and improve well/field production on a continuous basis.

PBTS COMPONENTS

Pressure Chamber

The PBTS pressure chamber is an engineered device custom designed to provide a buffer zone between the wellbore fluids and bubble tube gas. This unit has to be engineered and manufactured correctly, taking into account wellbore fluid properties, wellbore parameters, and operating conditions. Correctly designed, the pressure chamber will prevent wellbore fluids from entering the small bubble tube and potentially plugging it or causing erroneous readings. Refer to Attachment 1, Pressure Chamber.
This design has several benefits:

- Short mandrels can be easily made up to the completion string.
- Mandrel has identical drift and internal dimensions, and performance features (yield and tension) as the completion string.
- The pressure chamber can be easily modified in diameter and length to suit wellbore conditions
- All seals are metal to metal for long term leak free operation

From the volumetric and pressure constraints the chamber is sized to cover the complete operating range of the wellbore.
Chamber volume is calculated using the Ideal Gas Equation:
$(P_1 \times V_1) = (P_2 \times V_2)$

Substituting for standard gas values, yields;
$V_C = [(P_{MAX} . V_T)/P_{MIN}]-V_T$
Where:
V_C = Volume of Chamber
V_T = Volume of Bubble Tube
P_{MAX} = Maximum Pressure
P_{MIN} = Minimum Pressure

To account for uncertainties in operating pressures, the chamber is typical designed 25% larger than the calculated requirement.

Bubble Tube

This is the conduit for the gas to flow though from the bubble tube panel located on surface to the pressure chamber located at the bottom of the wellbore.
The bubble tube is available in various sizes, wall thickness and materials to meet wellbore conditions. The most common sizes used are the 1/8” x 0.035”

wall and the ¼” x 0.049” wall. Refer to Attachment 2, Bubble Tube Properties.
The bubble tube size is selected based on the following parameters.

- Chamber to tubing size ratio is affected by the wellbore operating pressures.
- Signal distortion.
- Mass storage and frictional effects.
- Protection of the tubing with coatings.

A balance needs to be maintained among the parameters to ensure the optimum size tubing and chamber is installed. As a general rule, the ¼” x 0.049” wall tubing should be installed when the chamber size will work with the specified wellbore conditions. This larger size tubing is allotted less prone to crushing and being damaged during the installation, frictional effects and typically does not require the protective coatings which can be very expensive in wellbore temperature greater then 150^{0}C.

Collar Protectors
The most susceptible location for damage to occur to the bubble tube is at the bottom and top of every collar. This type of damage occurs most often during the installation process. Collar protectors protect the bubble tube from being crushed or damaged from wear while it is being run into the wellbore.

Collar protectors used can be manufactured either of the one piece cast design connected with bolts or the pin type design. Both are used extensively in the industry and are very reliable and usable for multiple deployments. Both require additional rig time to install, which is dependant on the rig crew and number of lines. The only significant difference between the two types of collar protectors is the cost per unit. Typically, the cost for the bolt design is higher then the pin design. We have used both of them very successfully.

An alternative to the collar protectors used for supporting the weight of the tubing is the application of heavy steel banding material. Banding can be used with only the larger size bubble tubes and in applications where the wellbore is vertical and tubulars are small. This technique saves up to 30% of the downhole equipment cost (banding is 1/70th the cost of a protector) and can be applied about 80% faster than standard collar protectors, thereby saving considerable rig cost.

Termination
Exiting the wellhead with the bubble tube can be accomplished with several methods. The most widely used method is to terminate the bubble tube through the hanger and out through the casing bonnet. There are several important factors in the design

1. The bubble tube termination method and device must ensure well control is maintained at all times.
2. The design also must ensure that the bubble tube runs as a single (none spliced) tube from the bottom of the hole to surface and out of the wellhead. Early terminations inside the wellhead with the tube can result in potential problems if the connections become loose over time from cyclic wellhead temperatures. Gases like nitrogen are very difficult to seal, which is why it is always advisable to remove these connections from inside the wellhead.
3. The bubble tube, exiting the wellhead, as a single conduit must be protected from any and all possible physical damages from outside sources.

Bubble Tube Purging Gas
Typical gases used in conjunction with a bubble tube system are:

1. Nitrogen is probably the most common gas used in the Industry. It is inert, relatively inexpensive and generally easily obtained. It will not go though phase changes in the range of pressures and temperatures typically encountered.
2. Helium is the least preferred alternative due to the cost associated with it.
3. Natural Gas has been used, but leads to greater inaccuracies in the system due to the changing density and content of the gas.

Bubble Tube Purging and Monitoring Systems
These systems are typically set up to automatically purge the gas from an accumulator or pressure source, to the bubble tube. These systems are manufactured to control the purge cycle into one bubble tube and can be set up to continuously purge multiple wells and bubble tubes.

Bubble tube Manifolds are set up to include, but not limited to the following equipment:

1. Pressure regulator, reduces the pressure from

the source to the system.
2. Metering valve, used to regulate the flow of gas to a predetermined rate based on well conditions and sampling requirements.
3. Bypass valve, used to redirect the flow of gas for various reasons, from purging blockages in the system to working on the system
4. Solenoid valve turns on and off the flow of gas into a particular bubble tube for the purge cycle.
5. Electronic sequencing device, used to control the operation of the solenoid valves.
6. Leak proof check valves used to prevent the potential of any back flow of gas out of the well due to minute leaks in the many fittings in the panel as well as cross flow between the solenoid valves as they are sequenced.
7. Pressure transmitters, several styles are available based on the customers expected performance level and data requirements. PROMORE presently utilizes the ERD^{TM} sensor in non-intrinsic environments where the gas being used is Nitrogen. And Quartz transmitters in intrinsic environments where 0.01% accuracies and 0.0001% resolutions are required. Based on customer requirements switching valves can be utilized read multiple bubble tubes from one pressure transmitter, thereby reducing cost but also number of samples per minute.
8. Data acquisition system and smart cards used to log the data and control the purging cycle.

Refer to Attachment #3, Typical Bubble Tube Purging Panel

System Set-Up and Maintenance:
The PBTS is a partially closed system, which will operate without any operator intervention once the system is set up properly. Upon initial installation, the bubble tube is full of gas. When the well is put on production, the BHP will fall and the gas will be displaced from the bubble tube until a stable flowing pressure is reached. When the well is shut-in for build-ups or there are disturbances in the type of lift being used, the wellbore pressure will build up and compress the gas inside the pressure chamber. During the buildup and compression, a point will be reached where the gas compressibility will match the pressure exerted by the reservoir. Provided the minimum design pressure has not been reached, well bore fluids will not enter the bubble tube. The purge cycle will be initiated when the bottomhole pressure is 25% higher than the minimum design pressure.

Software Calculations
The computation of bottomhole pressure involves measuring the surface pressure and adding the calculated hydrostatic pressure of the gas in the bubble tube.

$\mathrm{BHP} = \mathrm{PRESS}_{\mathrm{SURFACE}} + \mathrm{P}_{\mathrm{HYDRO}}$

The ideal calculation of bottomhole pressure would involve knowing the temperature along the complete length of bubble tube in addition to the pressure at surface. Because this is impractical, an estimate of the average temperature of the gas column is made based on the measured bottomhole temperature measured at the bubble tube exit port and knowing the surface temperature. The bottom hole temperature measurement is made with either a thermocouple or with the PROMORE high temperature ERD^{TM} sensor.

The bottom hole pressure (BHP) calculation is simplified to the following form.

$\mathrm{BHP} = \mathrm{PRESS}_{\mathrm{surface}} + (\mathrm{PRESS}_{\mathrm{surface}} * \mathrm{G} * \mathrm{TVD})/(\mathrm{AWBT}+273.15)$

Where

$\mathrm{PRESS}_{\mathrm{surface}}$ = the measured pressure in kPa

AWBT = Average WellBore Temperature. This is estimated by measuring the Bottom Hole temperature

G = Gas gravity (nitrogen is 0.028762)

TVD = true vertical depth of bubble tube exit port

This calculation is valid for a static reservoir. Derivations of this equation exist for draw down and build up conditions, all of which can be programmed to determine pressure under a different condition.

ACCURACY, RESOLUTION, AND LIMITATIONS:

Definitions:

Accuracy - Is defined as how far the measured value can be from the true value. It is in effect your worstcase measurement error. Accuracy takes into account many effects such as hysteresis, non-linearity, and calibration errors.

Resolution - Is defined as the smallest detectable change in the measurand that can be detected by the instrument. It is how small of change can be resolved by the system. Resolution is always a smaller value than accuracy.

There are several factors that limit the accuracy, and resolution of the system as described above:

1. Sensor Measurement Resolution: The sensor resolution is predominantly a function of the pressure transmitters and the instrumentation taking the measurements. There are various transmitters available, as listed above.
2. Bubble Tube Effects: Several effects can take place when a remote measurement system is implemented with a bubble tube.
    - 2.1. Since the gas in the bubble tube is compressible, quick pressure changes can result in either compression or expansion of the gas within the bubble tube. This results in measurement error while the quick pressure transient is taking place. It is totally dependant on the viscosity of fluid compressing the gas in the bubble tube, the length and size of the bubble tube, and rate of change of the pressure transient.
    - 2.2. Another source of measurement error can result when the bubble tubes are either plugged or partially plugged with oil, sand, or another viscous fluid. Special attention has to be given to the design.
    - 2.3. A third source of error is in the estimation of the average temperature of the column of gas in the bubble tubes.
    - 2.4. A forth source of error can also occur if the oil displaces the gas in the bubble tube chamber and travels into the bubble tube. This condition may occur in designs not accounting for maximum pressure differentials and temperature cycles, or if there are gas leaks in the system.

Limitations

Bubble tube systems have several inherent limitations with regards to their accuracy, and capabilities. Some of the limitations are discussed below:

1. For the accuracy specification to hold true, the bubble tube must be purged with an inert gas, of known density and known temperature. Normally, the temperature of the gas column is estimated from the bottom hole temperature.

2. The bubble tube must be freshly purged with no oil, steam or water migration up the tube. A proper design of the bubble tube and chamber can prevent this from occurring.

3. The most accurate value is true immediately after purging the tube as the tube pressure comes back down to stabilize at the bottom hole pressure.

    - 3.1. If the average temperature of the bubble tube to surface is lowered, the gas inside the tube contracts and oil, water or steam will enter the bottom of the bubble tube chamber. This may result in lower readings if the migration of fluid proceeds into the bottom of the tube.

    - 3.2. If the pressure in the well-bore increases significantly between purge cycles, the gas in the tubes will be compressed by the oil, water, or steam entering the bottom of the bubble tube chamber. This will also result in abnormally low readings if the oil displaces the bubble tube chamber and enters the bubble tube. As a general rule, the more the bubble tubes are purged, the more accurate the data is between purge cycles, but as a result, more gas is injected into the formation.

4. During pressure buildup and fall-off tests, the reservoir may stay at a high temperature, with the majority of the bubble tube cooling down from the reservoir to surface because the well is no longer flowing. Since the gas density calculation is dependant on the downhole temperature measurement only, this can result in error in the gas head calculation.

5. Bubble tubes used in horizontal wells need to be as large as possible and be purged allot more frequently due to limitation of the bubble tube chamber. In horizontal wells the chambers are of

6. little use due to the flow profiles of the gas and fluids inside a tube.

CONCLUSIONS

- Long-term or continuous monitoring of BHP with gas can be accomplished with a bubble tube installation. The bubble tube is not limited by elevated temperatures, provides continuous long-term monitoring at negligible cost and is a rugged though less accurate alternative to an conventional permanent monitoring system.[1]
- The design and selection of the individual components are important to the success of the project.
- There are limitations to the system and must be understood before a project commences.

CONTACTS
FOR MORE INFORMATION

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LITERATURE CITED

[1] Duncan. G.,"Nitrogen determination of bottomhole pressure," World Oil. February 1997.

Attachment 1, Pressure Chamber

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Design Specifications
and Manufacturing Notes

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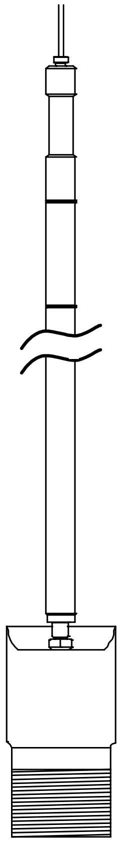
5-1/2" Tubing Mandrel with Bubble Tube Pressure Chamber



Overall Dimensional Data	
Length	Various
Maximum Running O.D.	6.30 in
Overall Weight	> 35 lbs

Mandrel Dimensional Data	
Length	Various
Mandrel Weight	Approx. 25 lbs
Maximum O.D.	7.663 in
Coupling O.D.	6.051 in
Internal Diameter	4.892 in
Drift Diameter	4.767 in
Tubing Weight	17.0 lb/ft
Thread 1	5-1/2" Vam Ace Box
Thread 2	5-1/2" Vam Ace Pin

Mandrel Performance Data	
Service Conditions	Sour
Material Grade	Incoloy 825
Internal Yield Pressure	7,740 psi
Collapse Resistance	6,280 psi
Minimum Material Yield Strength	80,000 psi
Maximum Material Yield Strength	95,000 psi
Minimum Tensile Strength	95,000 psi
Joint Yield Strength	326,000 psi

Pressure Chamber Dimensional Data	
Length	Various
Maximum O.D.	1 11/16"
Gauge Weight	Various

Pressure Chamber Specifications	
Service Conditions	Sour
Wetted Part Material	Incoloy / Hastelloy
Non-Wetted Material	Incoloy / Hastelloy
Non-Critical Material	Incoloy / Hastelloy
Sensor Count	Pressure Port
Temperature Rating	-20°F to 800°F
Working Pressure	10,000psi
Collapse Resistance	11,260 psi
Tubing Head	1-11/16" Clamp Style
Mandrel - Chamber Seals	15,000 psi Metal-to-Metal
Chamber - BT Line Seals	Dual Metal-to-Metal

Attachment 2, Bubble Tube Properties

Theoretical Internal Working & Bursting Pressures

For Welded Types 304 & 316 Stainless Steel Tubing at -20°F to +100°F

Size (Inches)		Gauge No.	Internal Pressure (psi)	
O.D.	Wall		Working	Burst
1/8	.020	25	6,000	24,000
	.028	22	8,400	33,600
	.035	20	10,500	42,000
1/4	.020	25	3,000	12,000
	.028	22	4,200	16,800
	.035	20	5,250	21,000
	.049	18	7,350	29,400
	.065	16	9,750	39,000
	.083	14	12,450	49,800

Service Pressure

The ASTM tubing specifications do not include any recommended service pressure or any elevated temperature pressure requirements. However, throughout the tubing and pipe industry, Barlow's Formula is commonly used to estimate the theoretical internal bursting and working pressures of tubing.

Simply stated, Barlow's Formula is:
$P=2St/D$

Where:
P=Burst pressure, psi
S=Tensile strength of material, psi (75,000 psi for types 304 & 316)
t=Wall thickness, inches
D=Outside diameter, inches

Using this formula, reasonable estimated burst pressures can be calculated. Yield pressures can be estimated as well by substituting "Y" (yield strength of material, psi) for "S" in the formula. A reasonable working pressure is derived by dividing the estimated burst pressure by 4, yielding a 4 to 1 safety factor margin. Note that actual burst values may vary from the theoretical values listed in the table above due to variations such as actual wall thickness, diameter to wall ratios, material properties and installation conditions. These theoretical values, however, are adequate for estimating required tubing sizes.

Collapse Pressure

Various outside factors such as installation, bending, etc. must be considered when calculating collapse pressures. Therefore, we suggest contacting your PROMORE Sales Rep for information concerning collapse pressure

Composition (%) of Austenitic Stainless Steel & Nickel Alloys

Grade	316	316L	825	Duplex 2205
UNS Designation	S31600	S31603	N08825	S31803
Carbon (C) max.	0.08	0.035*	0.05	0.03
Manganese (Mn) max.	2.00	2.00	1.00	2.00
Phosphorus (P) max.	0.04	0.04	-	0.03
Sulphur (S) max.	0.03	0.03	0.03	0.02
Silicon (Si) max.	0.75	0.75	0.50	1.00
Chromium (Cr)	16.0 to 18.0	16.0 to 18.0	19.5 to 23.5	21.0 to 23.0
Nickel (Ni)	10.0 to 14.0	10.0 to 15.0	38.0 to 46.0	4.5 to 6.5
Molybdenum (Mo)	2.0 to 3.0	2.0 to 3.0	2.5 to 3.5	2.5 to 3.5
Other Elements	-	-	Fe=Bal Cu=1.5 to 3.0 Al=0.2 max. Ti=0.6 to 1.2	N=0.08 to 0.20

Physical Properties of Stainless Steel & Nickel Alloys in the Annealed Condition at -20°F to +100°F

*** Tensile and yield strengths are minimums.**

Alloys	Tensile Strength (psi)*	Yield Strength .2% Offset (psi)*	Elongation in Two Inches (%)	Modulus of Elasticity (10^{-6} psi)	Coefficient of Thermal Expansion (in./in./°F x 10^{-6})
316	75,000	30,000	35	29.0	9.2
316L	70,000	25,000	35	29.0	9.2
Alloy 825	85,000	35,000	30	28.0	7.7
Duplex 2205	90,000	65,000	25	27.5	7.6

Sizes and Coil Lengths:

Size (Inches)		Maximum Coil Lengths (Feet)	
O.D.	Wall	Without Orbital Welds at Finished Size	With Orbital Welds at Finished Size
1/8	.028	15,000	-
	.035	15,000	-
1/4	.035	10,000	40,000
	.049	10,000	40,000
	.065	4,000	40,000
	.083	3,000	40,000

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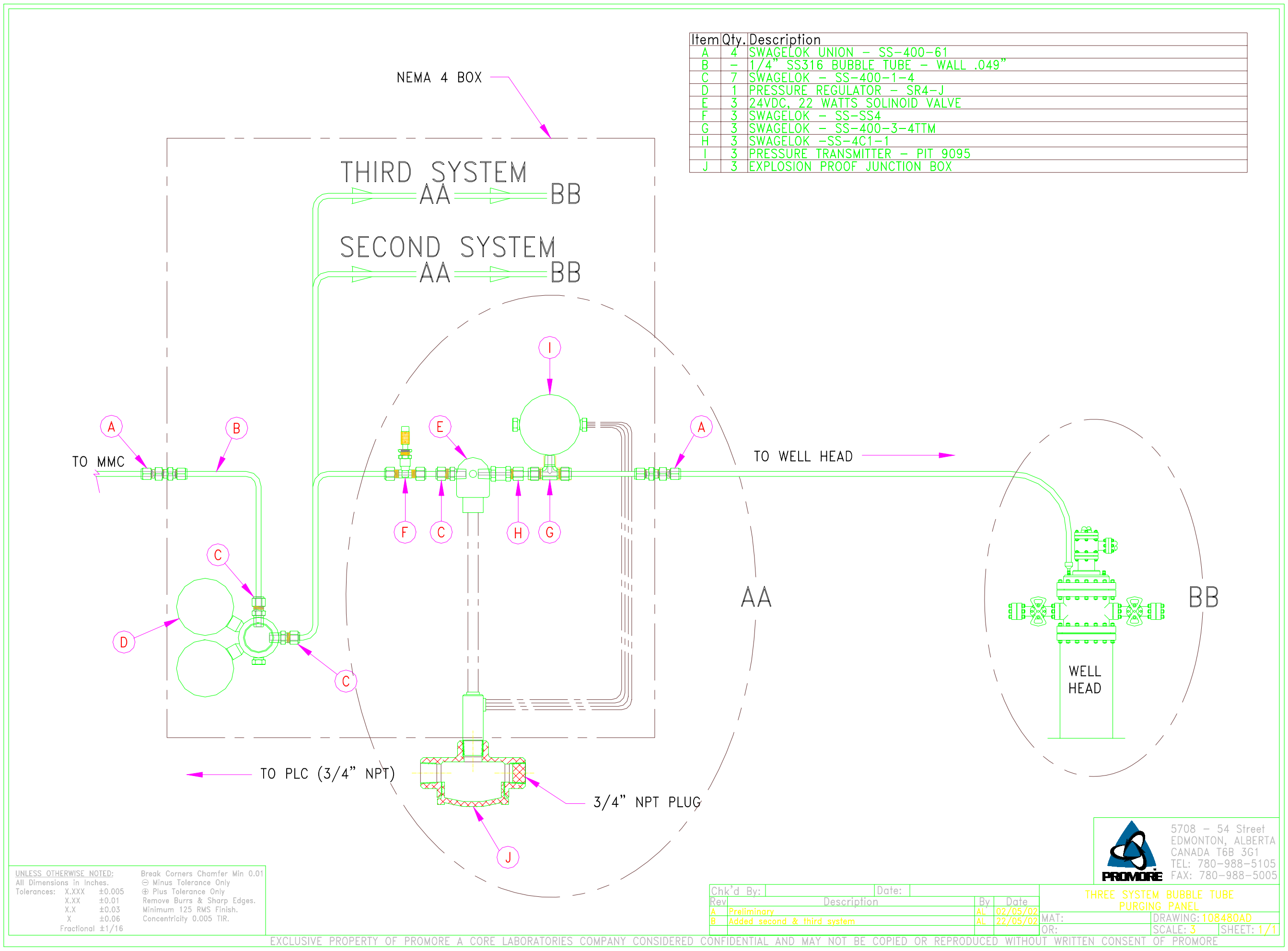
Attachment #3, Typical Bubble Tube Purging Panel



Item	Qty.	Description
A	4	SWAGELOK UNION – SS-400-61
B	–	1/4" SS316 BUBBLE TUBE – WALL .049"
C	7	SWAGELOK – SS-400-1-4
D	1	PRESSURE REGULATOR – SR4-J
E	3	24VDC, 22 WATTS SOLINOID VALVE
F	3	SWAGELOK – SS-SS4
G	3	SWAGELOK – SS-400-3-4TTM
H	3	SWAGELOK -SS-4C1-1
I	3	PRESSURE TRANSMITTER – PIT 9095
J	3	EXPLOSION PROOF JUNCTION BOX

Chk'd By:		Date:	
Rev	Description	By	Date
A	Preliminary	AL	02/05/02
B	Added second & third system	AL	22/05/02