Paper 27

Flare Meter Monitoring Method, and Flare Meter High Velocity Extender

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21st NORTH SEA FLOW MEASUREMENT WORKSHOP 2003

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FLARE METER MONITORING METHOD, and FLARE METER HIGH VELOCITY EXTENDER
Experience from Snorre TLP High Pressure Flare Estimator Pilot.

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1. INTRODUCTION

This is about an innovation breakthru for flare metering, and its pilot test at Snore TLP. Yet there are no new equipment in this pilot test. Anywhere where there is a flare installed, the necessary basic equipment is already in place.

As long as there has been platforms producing in the North Sea, production personell have looked to the flare for information when our prudent flare meters have failed. Windows in the control room have been equipped with scales per the flare flame size. Others have looked for restrictions in the flare line that could be used for flare meter checking, and some have been lucky to find a 90 degree elbow that could be used for the purpose, mainly at higher flowrates.

At the Snorre TLP startup after the 2002 authumn shutdown , the flare flowrates were very high – far more than the fiscal flare meter could handle. At this time the Snorre TLP production engineer Atle Alvestad and the NPD representative Steinar Fosse looked at the flare tip, and saw a potential flow meter.

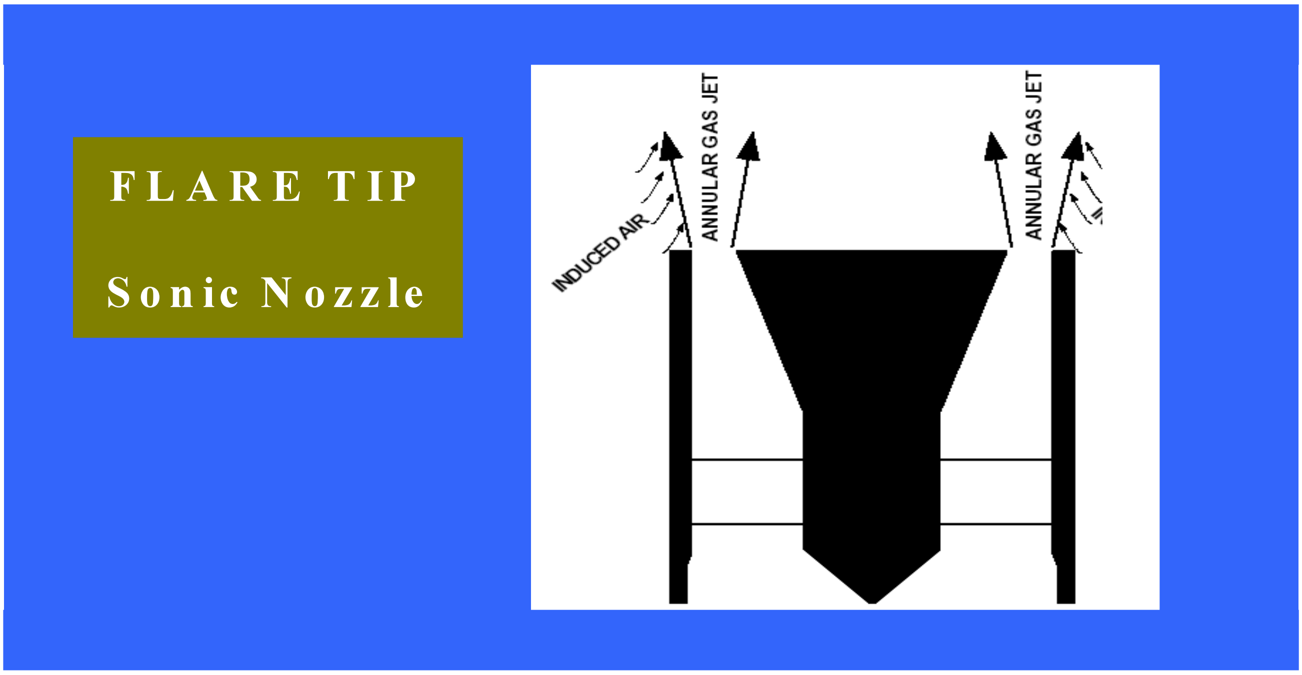

Figure 1. Flare Tip Sonic Nozzle

I was challenged to make an empirical relation beween the Snorre TLP flare flowrate and the pressure in the flare line, based on flare tip characteristics.

2. FLARE TIP CRITICAL NOZZLE

An equation that could be applied to the flaretip flow correlations was basically already available. At the higher flowrates, where velocity of sound is the limiting factor for the maximum flowing velocity, the Critical Nozzle equations was a good starting point. In essence; viewed from the access point immediately upstream of the flare tip :

$$Q\ (Sm3/time) = Const * SQRT(dP * Dens) / Std\ dens \qquad (Eq.\ 1)$$

with $$dP = Kr * P_{a,tip} \qquad (Eq.\ 2)$$

where Kr is an almost constant variable for Hydrocarbon gasses.

and $$Density = P_{a,tip} * MW / (0{,}0831451 * (T_{tip} + 273{,}15) * Z_{tip}) \qquad (Eq.\ 3)$$

The flaretip flow correlation below critical velocities, is regarded as a regular flow element, with equations 1 and 3 still valid, but with differential pressure :

$$dP = P_{a,tip} - P_w$$

where Pw is the athmospheric pressure for the platform at that moment.

This ties the two parts of the flare performance curve togetheter, into correlations that was easier to handle than I had expected.

3. FLARE TIP PRESSURE AND TEMPERATURE

The flaretip temperature and pressure were available immediately upstream of the flare tip restrictions when the Snorre TLP plattform was initially started in 1992. Both transmitters were removed at an early stage, because they were in a difficult position to serve and they provided no necessary information at that time.

This position is normally at least three meters below the flame, and could be included in a flare tip. However, the flare tip temperature should be expected around 60 degrees: Heat exchange between cold flare gas with flame energy, will balance higher velocities with increasing flame energy. The flare tip pressure can be calculated from the pressure measured at the installed flare meter position. I used the Darcy friction loss equation, modified to account for a significant pressure loss. Also the gas height pressure is included in this flare tip pressure calculation :

$$P_{a,tip} = P_{a,m} - 0{,}185 * L * f * (Q\ (Sm3/time)^{2}) * MW * T_m / (P_{a,tip} + P_{a,m}) / D^{5} - 0{,}00061 * H * MW * (P_{a,tip} + P_{a,m}) / T_m \qquad (Eq.\ 7)$$

L is Friction Length in meters , from the used pressure transmitter up to the flare tip restrictions.
f is Friction Factor.
Tm is average temperature in this part of the flare stack from the flare meter; approximate 300 degK.
H is flare height in meters, from pressure transmitter up to the flare tip restrictions.
D is diameter in mm.

For the highest flowrates, the flare tip pressure from these calculations will normally be around 90 % of the reading from the pressure transmitter at the flare meter.

4. SNORRE TLP PILOT WITH SIMPLIFIED EQUATIONS

The flare tip pressure model was used to derive at values for an adjustment factor from the pressure transmitter reading for the Snorre TLP pilot Flare Estimator :

$$Pa,tip = Cf * Pa,m \qquad (Eq.\ 9)$$

In the calculations for the pilot Flare Estimator, the flare tip upstream temperature was set to 56 degrees C.

Up to and included Pa,tip equal critical flow pressure , the Flare Estimator is :

$$\mathbf{Q\ (Sm3/hr) = C1 * SQRT(Pg,tip * Pa,tip)} \qquad (Eq.\ 10)$$

and for Pa,tip above critical flow pressure , the Flare Estimator is :

$$\mathbf{Q\ (Sm3/hr) = C2 * Pa,tip} \qquad (Eq.\ 12)$$

The Cf equation, C1 and C2 constants helped us to avoid complex equations for the pilot test.
The full set of equations that these are derived from, are made available in the back of this paper.

5. PILOT TESTING OF FLARE ESTIMATOR FOR MONITORING

The Flare Estimator pilot was installed for online calculations in the Central Machine of the Snorre TLP measurement computer system by FMC Kongsberg Measurement. This included Standard Volume flow rate calculations, hourly totalizer reports and most important ; simultaneous trending of the existing flare meter and the Flare Estimator. The trending can provide totalizer readings at any chosen moment.

The Flare Estimator pilot approach for Snorre TLP high pressure flare was proven an amazing breakthru for Flare meter monitoring. For velocities around 50 m/sec, the flare tip restriction differential pressure based Flare Estimator tracks a proper functioning flare meter almost moment by moment. In this way the expected shortcomings and malfunction of existing flare meters can now be monitored closely.

The Flare Estimator flow and volume results for higher velocities above 50 m/sec, can also be used to correct for frequent malfunction of flare meters - as a valuable Flare Meter High Velocity Extender for the presently available flare meter technology. The flare meter results is compared on an hourly basis, or for shorter intervals based on trend reading of the totalizers in the Flare Estimator pilot.

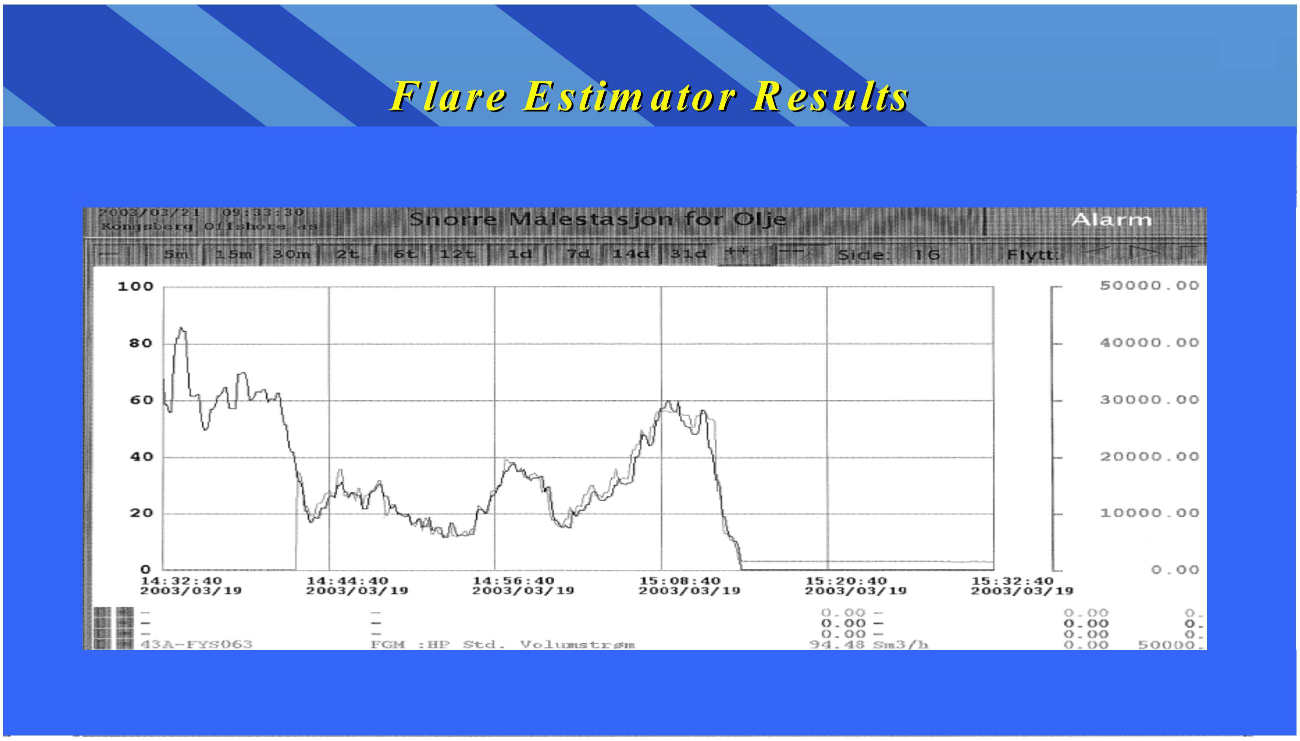

Figure 2. Flare meter tracking Example

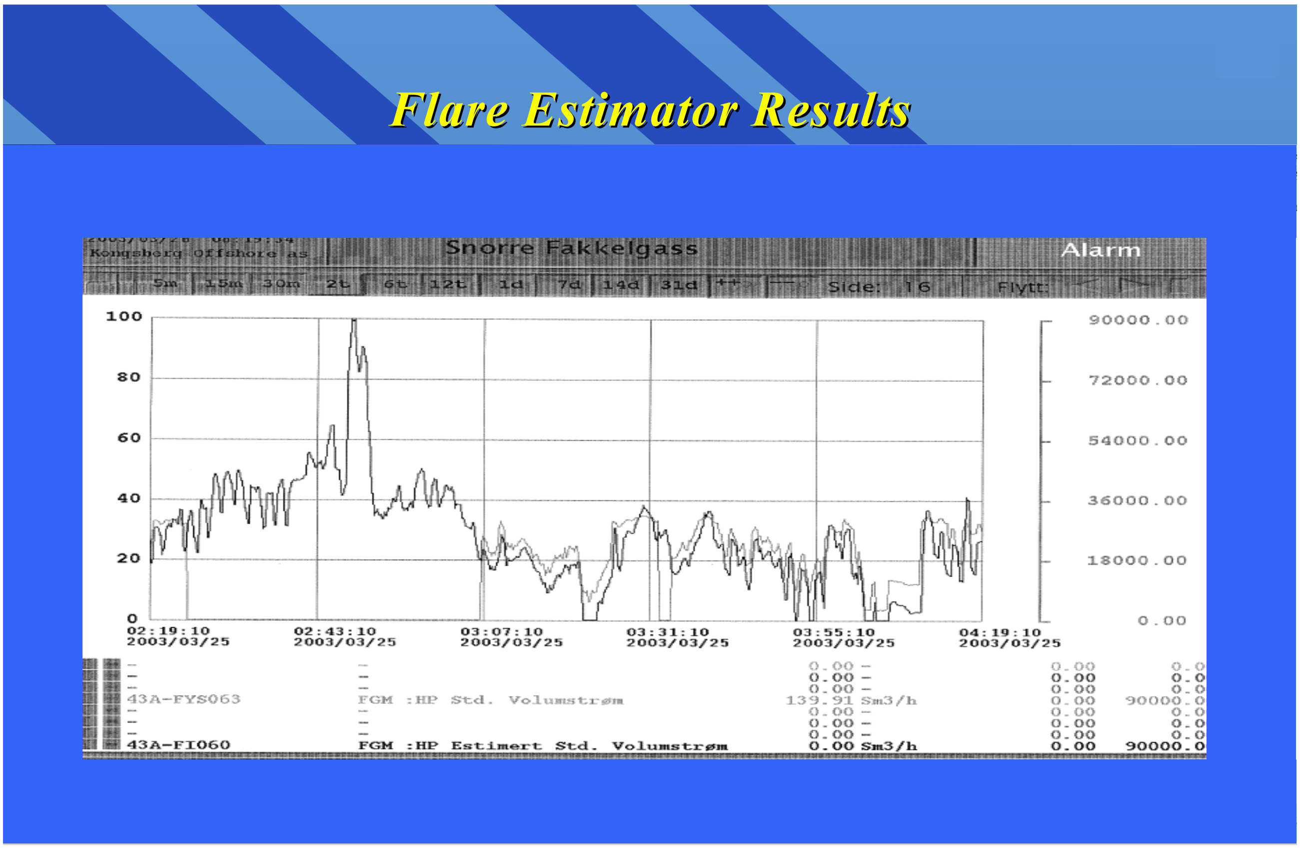

Figure 3. Flare Meter Extender Example

6. CRITICAL NOZZLE FACTOR

The critical pressure factor Kr is as for Critical Nozzles; a ratio varying with different type of gasses. For Hydrocarbon gasses and with the low pressure flare stack condition, the Kr factor is expected to be close to constant. Some challenging work in this area is left for others. Used Kr factor of 0,34 matches the performance curve from the flare tip manufacturer for the Snorre TLP flare tip. This perfomance curve was used as a starting point for the Flare Estimator Pilot.

7. FLARE CRITICAL NOZZLE CALIBRATION

Excluding gas expansion factor influence, a complete calibration can be based on two points. To be sure that this point is in the critical flow region; calibration with a flare tip pressure close to 2 BarA would satisfy. If higher calibration flowrates are practical, this would confirm the high end curve.

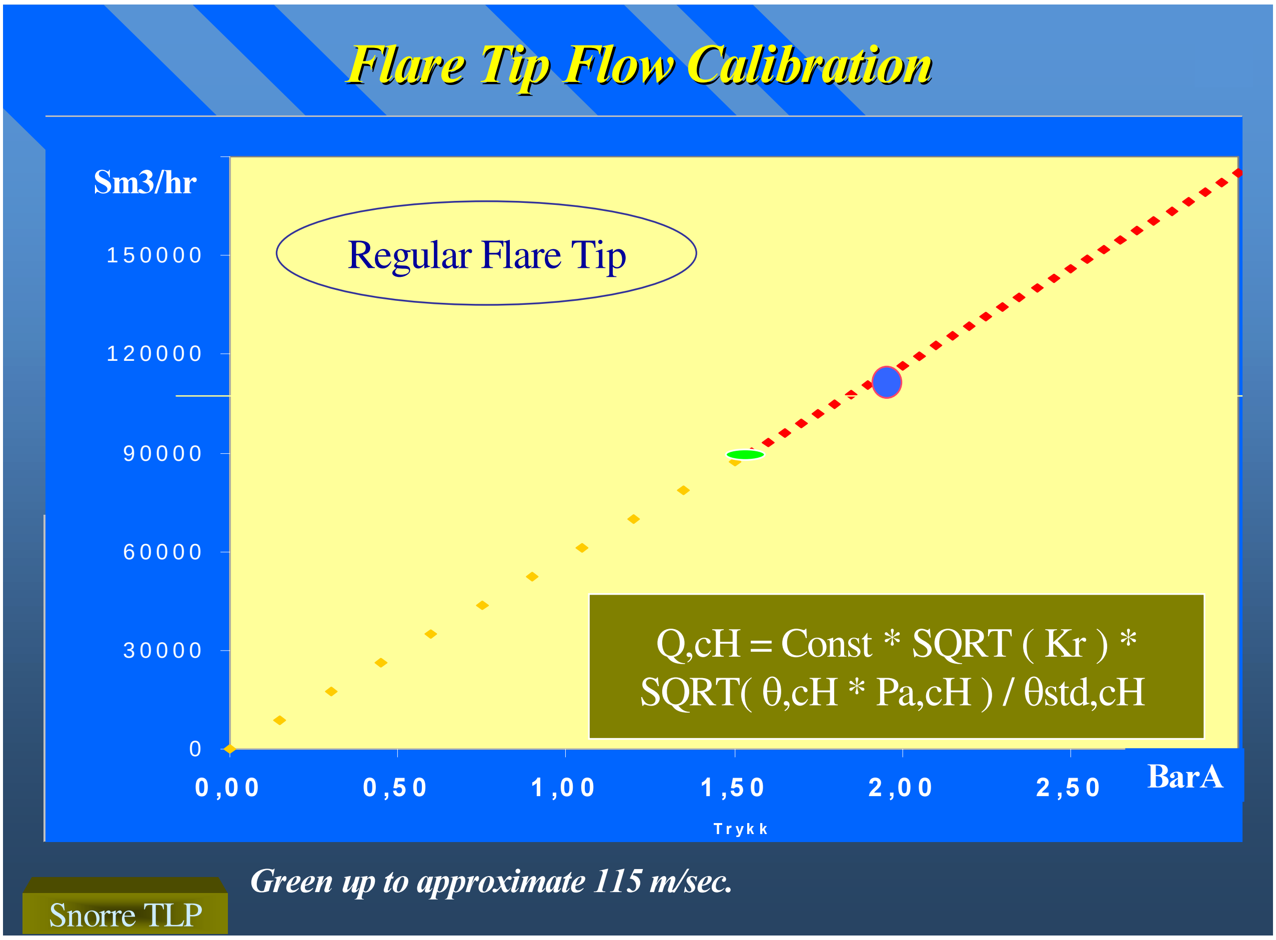

Figure 3. Velocity of sound limited high end calibration of Flare Tip Critical Nozzle

Other calibration gasses than Hydrocarbon gasses would require Kr factor adjustment, to be valid for real flare determination. Kr factor for Nitrogen is expected to be around 5 % higher.

In the lower region flare tip of 1,25 BarA is recommended : The flow meter is likely to function still.

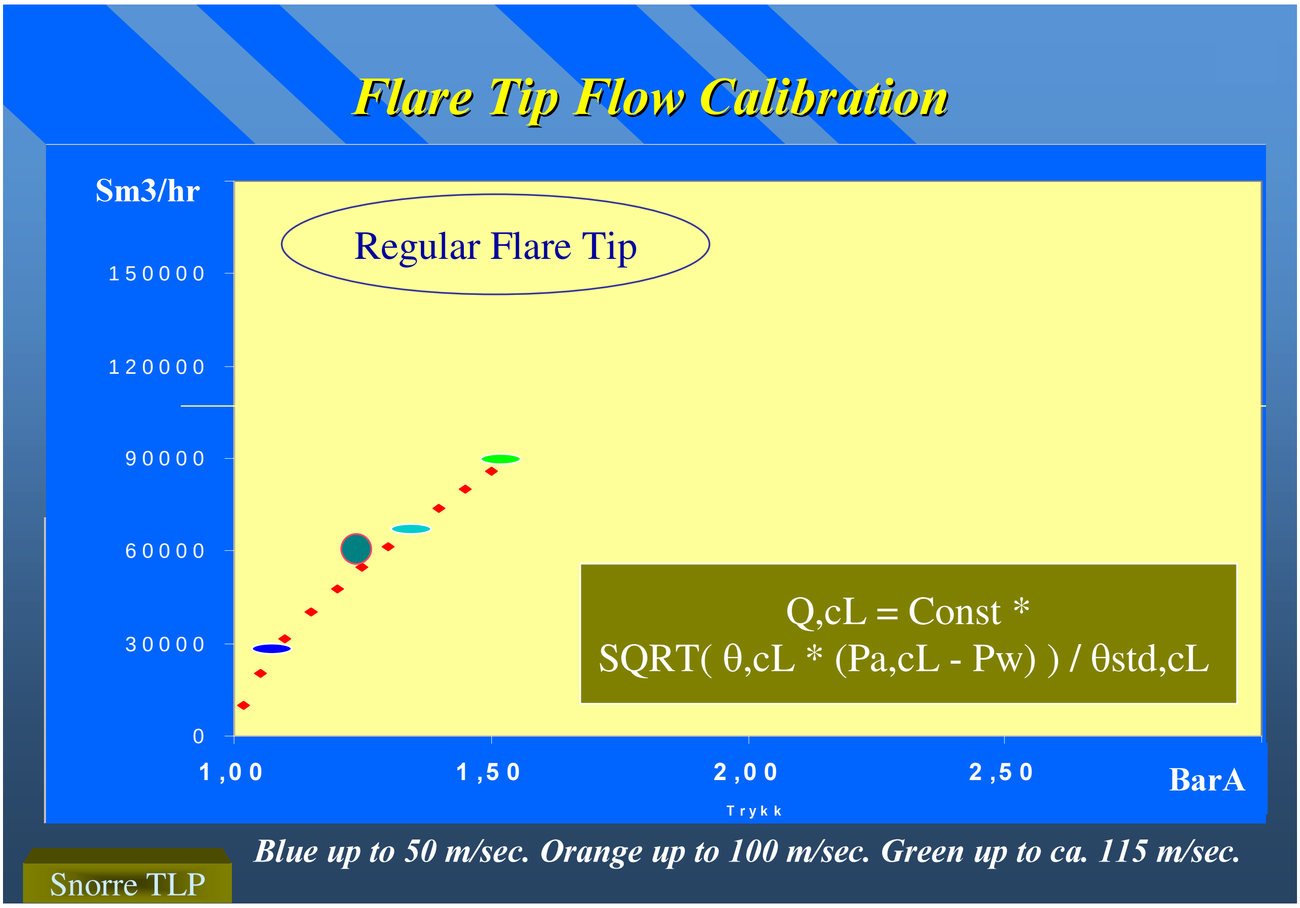

Figure 4. Lower velocity end calibration of Flare Tip Critical Nozzle

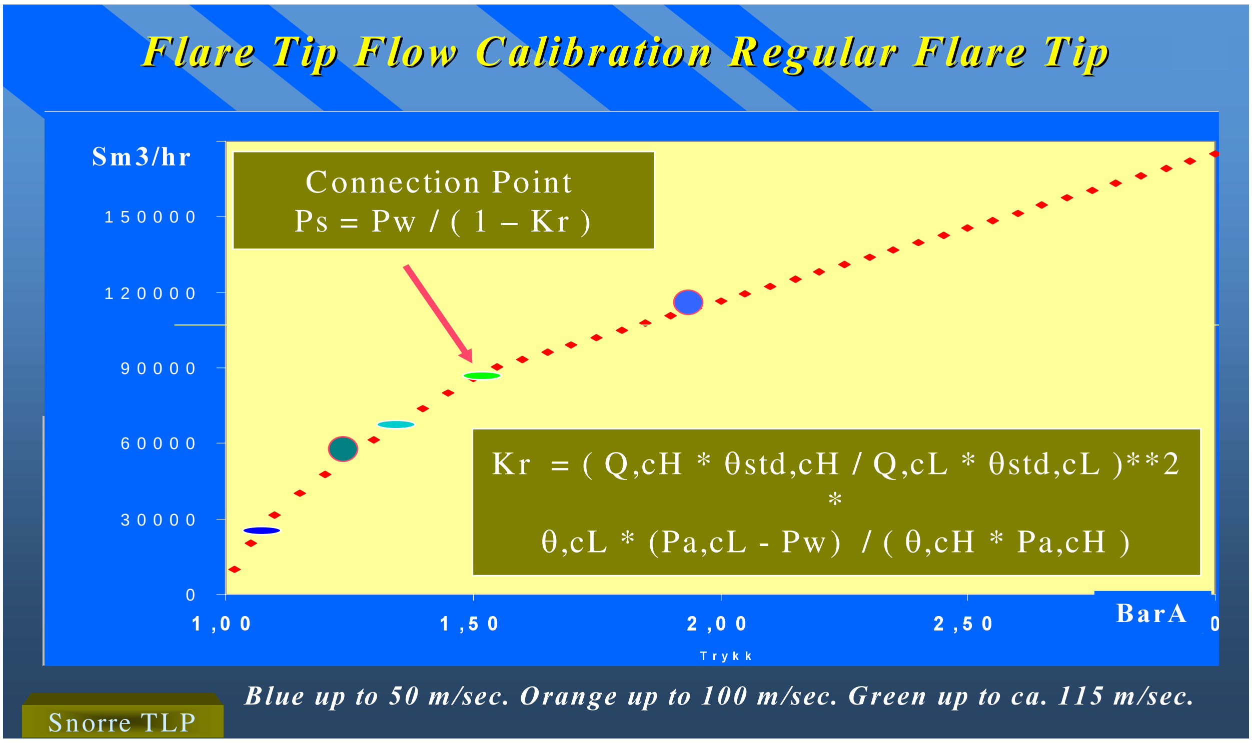

Figure 5. Flare Tip Critical Nozzle calibration Critical Pressure Point

8. FLAP FLARE TIP PERFORMANCE

For the flap type flare tip, an intermediate velocities empirical equation is introduced to fill the gap; covering from flap movement start velocities up to the start of critical velocities as limited by the velocity of sound.

In the low end before the force is strong enough to move the flap, the flow equation will be simular to that of the regular flare tip in the low flow region.

Pa,tip = Flap Movement Limit Pressure BarA , estimator :

Q (Sm3/hr) = C1 * SQRT (Pg,tip * Pa,tip) (Eq. 10)

Further up to and including critical flow limit;
Pa,tip = Flap Fully Open Limit Pressure , empirical equation for the Flare Estimator is :

Q (Sm3/hr) = Cflap0 + Cflap1 * (Pa,tip - Pref) + Cflap2 * (Pa,tip - Pref)2** (Eq. 11)

og for Pa,tip over Flap Fully Open Limit Pressure , the Flare Estimator is :

Q (Sm3/hr) = C2 * Pa,tip (Eq. 12)

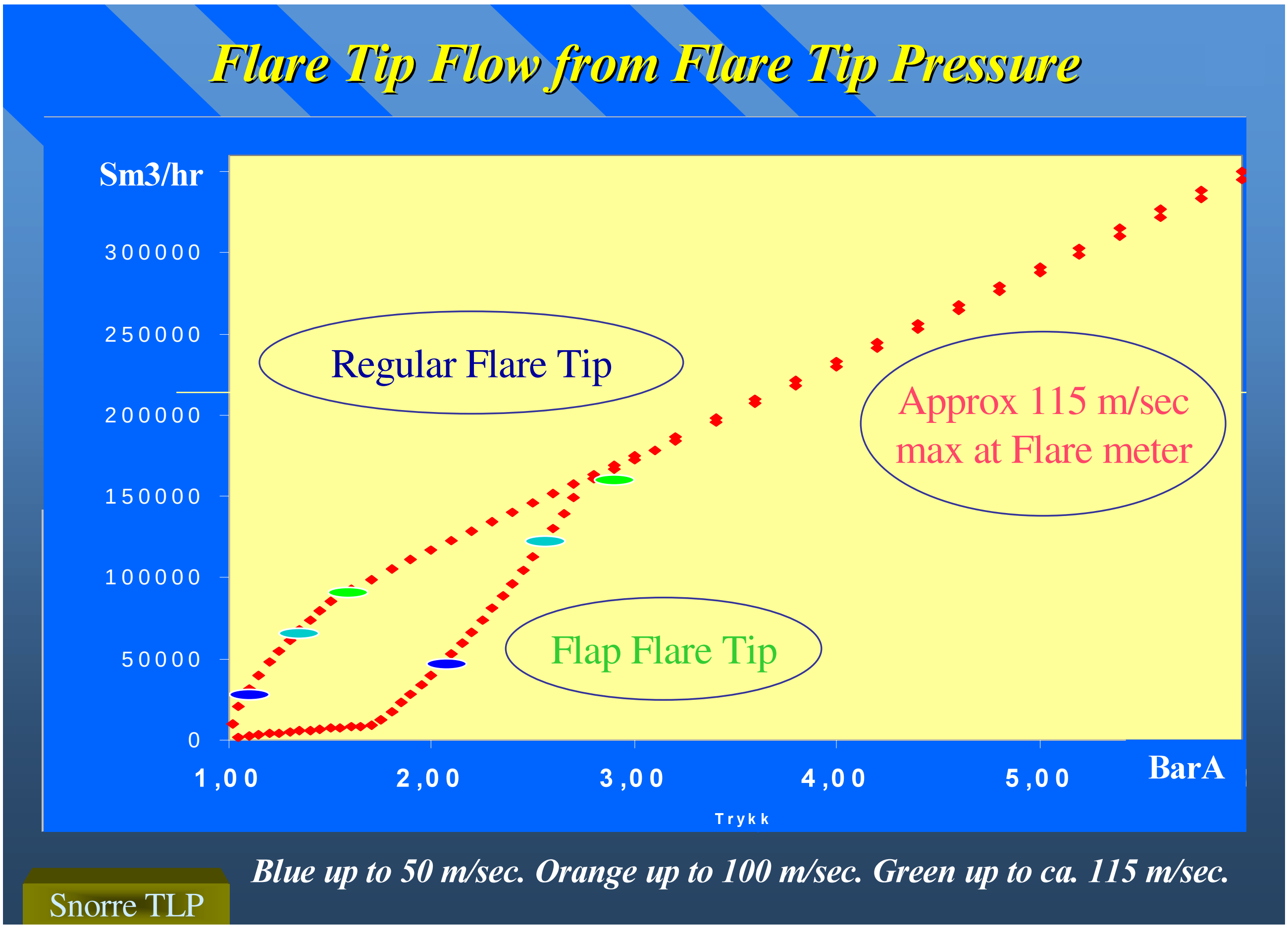

Figure 6. Snorre TLP Flap Flare Tip Performance compared with Regular Flare Tip

9. LOW FLOW CHALLENGES

Gas expansion effect is not considered. Some challenging work in this area is left for others.

The pilot Flare Estimator uses gauge pressure transmitter only. Especially at the low end, the differential force depends on the real atmospheric pressure at the platform. For instance 0,02 Bar differential pressure from the flare tip is estimated to approximate 10 000 Sm3/hr with an average velocity close to 25 m/sec for the Snorre TLP flare. To get reasonable flow indication at the low end, it is necessary to include an athmospheric pressure measurement. However, already with 0,1 Bar differential pressure, this error is reduced inside 3 000 Sm3/hr (approximate 10 % of flowrate).

Even with an athmospheric pressure transmitter included, it remains to predict the wind ejector effect, that can be significant for the lower flowrates. These effects will be in the same order as for the athmospheric pressure variations. It is therefore not expected, that existing flare meter technology can be competely replaced by flare tip restriction based calculations.

10. MOLWEIGHT INFLUENCE

At least before the flaring starts, the flare gas molweight is normally unknown. The flare MW is recommended to be set to match the normal flaring composition. When knowledge of these parameters are available afterwards, the Flare Estimator results can be further compensated :

Multiplier for final result Sm3/hr is approximate : SQRT (Used MW / Real MW).
The remaining error after a 10 % change in MW is then well inside 0,1 %.

ATTACHMENT

SNORRE TLP FLARE ESTIMATOR DEVELOPMENT CALCULATIONS

Flare Tip Restriction Based Calculation

Flare tip pressure in BarA : Pa,tip
Pg,tip = Pa,tip – Pw

Pw is from the weather station

Flaretip temperatur in degC : Ttip , expected between 50 til 60 degC.

Q (Sm3/time) = Const * SQRT (dP * Dens) / Std dens (Eq.1) with dP = Pg,tip however maximum Kr * Pa,tip (Eq. 2)

Density = Pa,tip * MW / (0,0831451 * (Ttip + 273,15) * Ztip) (Eq. 3)

Flare tip, Snorre TLP Hydrocarbon gasses , 1 to 7 BarA, 40 til 70 degC :

$1 / Ztip = 1 + 10^6 * (1,1725034 - 0,15972574 * MW + 0,010701654 * MW^2) * Pa,tip / (Ttip + 273,15)^{3,6}$

(Eq. 4)

Std. Density = 1,01325 * MW / (0,0831451 * 288,15 * Zref) (Eq. 5)

Flare ; $Zref = 1 + 0,0000505298 * MW - 0,00001078323 * MW^2$ (Eq. 6)

Calculated Flare Tip Pressure

HP flare pressure measurement in BarA. Hereafter Pa,m.

Calculated Cf flare tip pressure ratio is determined from pressuredrop estimated for curvefit approximation , based on a modified Darcy friction relation :

Pa,tip = Pa,m - 0,185 * L * f * (Q (Sm3/time)**2) * MW * Tm / (Pa,tip +Pa,m) / D**5
- 0,00061 * H * MW * (Pa,tip + Pa,m) / Tm

(Eq. 7)

L is Friction Length in meters , from the used pressure transmitter up to the flare tip restrictions.
f is Friction Factor.
Tm is average temperature in this part of the flare stack from the flare meter; approximate 300 degK.
H is flare height in meters, from pressure transmitter up to the flare tip restrictions.
D is diameter in mm.

Flare Estimator

Pressuredrop Cf flaretip factor with curvefit approximation :

Cf is set to Fmax up to P1 BarA . Up to and including P2 BarA :
Cf = (F0 + F1 * (Pa,m - Pref) + F2* (Pa,m - Pref) * *2 (Eq. 8)
However with minimum value ; Fmin.

Above P2 BarA ; Cf is set to minimum value Fmin.
Note that Cf is almost constant for critical flowrates.

Flare tip pressure estimate in BarA :
Pa,tip = Cf * Pa,m (Eq. 9)

Up to and included Pa,tip equals Limit Pressure Pt1 in BarA ,the Flare Estimator is :

Q (Sm3/hr) = C1 * SQRT (Pg,tip * Pa,tip) (Eq. 10)

Further up and including critical flow limit;
Pa,tip = Flap Fully Open Limit Pressure; Pt2 in BarA, the empirical equation Flare Estimator is :

Q (Sm3/hr) = Cflap0 + Cflap1 * (Pa,tip - Pref) + Cflap2 * (Pa,tip - Pref)2**

(Eq. 11)

og for Pa,tip above critical flow or over Flap Fully Open Limit Pressure Pt2 , the Flare Estimator is :

Q (Sm3/hr) = C2 * Pa,tip (Eq. 12)

Q (Sm3/hr) is continuously integrated into Qhour in Sm3.
Qhour from previous hour is reported for possible correction purposes.

Snorre TLP Flare Estimator calculation is based on MW 23,5 (1 Kg/ Sm3) and fixed temperature Ttip (56 deg C)

Snorre TLP Regular Flare Tip **(Kr ≈ 0,34)**

Fmax	= 0,9960	Pt1	= Pw/(1-Kr) ≈ 1,53 BarA
P1	= 1,01 BarA	C1	= 100 000
P2	= 1,74 BarA	Pt2	= Pw/(1-Kr) ≈ 1,53 BarA
F0	= 0,9960	Cflap0	= NA
F1	= - 0,2373	Cflap1	= NA
F2	= 0,12385	Cflap2	= NA
Fmin	= 0,8888	C2	= 58 300

Snorre TLP Flap Flare Tip

Fmax	= 0,9960	Pt1	= 1,71 BarA
P1	= 1,8 BarA	C1	= 8230
P2	= 3,096 BarA	Pt2	= 2,75 BarA
F0	= 1,0347	Cflap0	= - 32 500
F1	= - 0,0388	Cflap1	= 25 100
F2	= - 0,01438	Cflap2	= 48 700
Fmin	= 0,8912	C2	= 57 500

When different molweight is known ; multiplier for final Sm3/hr is :

SQRT (23,5 / MW)

When different flaretip temperature is known ; multiplier for final Sm3/hr is

SQRT (329,15 / (Ttip + 273,15))

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.