PRACTICAL FIELD OPERATION OF COMPACT PROVERS FOR MASTER PROVING

by

M BAYLISS

OCCIDENTAL PETROLEUM (CALEDONIA)

PAPER 5.3

NORTH SEA FLOW METERING WORKSHOP 1984

16-18 October 1984

National Engineering Laboratory
East Kilbride, Glasgow

PRACTICAL FIELD OPERATION OF COMPACT PROVERS FOR MASTER PROVING

M.D.H. Bayliss

Although compact provers have been commercially available in the USA for several years, their use in the UK has only recently been accepted by regulatory bodies. This acceptance has not been granted generally but permitted on an application-by-application basis only.

This paper describes the first permitted uses, as a special case, on live crude oils for annual master proof recalibration of UK offshore platform pipe provers. Techniques were developed to use the small volume and high speed of operation of a compact prover to its greatest advantage and improve upon the traditional API[1] methods of proving.

INTRODUCTION

Occidental Petroleum (Caledonia) Ltd. operates an oil pipeline on behalf of a consortium to their terminal on Flotta, Orkney. The live crudes feeding the line are exported from their Piper and Claymore platforms as well as Texaco's Tartan installation. Each platform has fiscal metering stations for crude oil using positive turbine meters and a bi-directional pipe prover.

Annual master proving calibration is required by the Department of Energy and until 1983 had been carried out using a portable pipe prover. This was normal practice in the UK sector of the North Sea and involved the use of one of two purpose built units which were both large and heavy. On Piper platform, the master proving exercise involved the temporary removal of a stairway each year and on both Piper and Claymore the access in the area was considerably reduced. Although physically large units, the portable pipe provers had very restricted flow capability which created difficulty in launching the sphere of the platform prover due to the sphere receiver design. It was thus with great interest that the availability of a compact prover in the UK was greeted.

One of the metering calibration companies was able to offer a 14" Brooks Compact Meter Prover in time for the 1983 master proving on Piper and Claymore. Details of the construction and principles of operation of this device have been described by Wolf[2] and are also available in manufacturer's literature[3]. On informal application to the Department of Energy there was naturally reluctance to permit the use of a device which had no local user history, particularly on live crude. Compact provers had been used in the Norwegian Sector of the North Sea but the only available data related to their use on diesel fuel circulated by a pump rather than using the process fluid.

Generally, there seemed to be a lack of confidence in a piece of equipment which had been produced in some quantity in the USA with good user experience. Doubts were expressed about leakage past the piston and poppet valve seals where dynamic checking of the leak rate was not possible, though static tests were demonstrably good. A number of trials were carried out but authorities remained sceptical about successful proofs on light hydrocarbon products being repeated on live crudes.

The advantages of using a compact prover offshore decided the writer to proceed independently with master proofs on a trial basis, since the authority's requested "double trial" using a portable pipe prover alongside the compact unit could not be readily accommodated offshore. It was agreed with the Department of Energy that the results obtained would not automatically be accepted but be reviewed along with other data from land-based proofs on petroleum products and water. Clearly, to gain the necessary experience with the unit on live crude, someone had to be first!

OFFSHORE MASTER PROVING PREPARATION

Both Piper and Claymore crude oil metering systems operate on a continuous basis, the flowrate being determined by the levels in the production separators, Fig. 1 q.v. Level Control Valves are placed, somewhat unconventionally, downstream of the meters but before the branch to the prover header, necessitating liquid compressibility corrections to the routine meter proofs. One meter is dedicated to each separator with a common spare. On Piper, flow to the master prover is achieved by pinching back the appropriate meter run valve with its associated prover diverter valve being fully opened. Claymore platform has the facility, schematically shown in Fig. 2, to feed crude from the test separator through the prover and return it to either of the production separators. This is ideal for master proving, since it enables one or two individual wells to be routed through the prover on their own. Claymore well characteristics vary considerably - wells featuring dry production, steady flow and low density being favoured for master proving.

The master prover connections on both platforms are the usual 3" 300 lb ANSI flanges, teed off the platform pipe prover discharge line. To ensure isolation of this line during master proving a line blind (spade) is fitted on Piper, a double block-and-bleed valve serving the same purpose on Claymore. For the initial trials, the compact prover was connected to its separate 3" turbine reference meter by means of flexible hoses, this being improved later to a fixed piggy-back mounting over the top of the prover barrel. The tie-in was thus similar to that used for a portable loop prover, though the improved access around the compact prover was immediately obvious with no walkways or stairs being significantly obscured.

Shipping the compact prover had been a simple task involving only a 1-1/2 ton lift into a standard container, the electronics and water-draw can being separately packed into the same container. Loaded forward on the supply boat to minimise seawater ingress, the container was handled normally onto the platform skid deck along with other containerised cargo. The prover could then be rolled out on its large castors and lifted to the laydown area adjacent to the calibration connections, being finally moved by hand to the best position. Portable pipe provers had always been an awkward lift of 6-7 tons down to this area with the best position made inaccessible to the crane by an overhead walkway.

Normal preparations for the master proof, such as spading the platform prover drains where necessary and checking for leakage at appropriate valves, were carried out. The annual full maintenance programme had been carried out a few weeks before to change out the platform prover sphere and 4-way valve slips, check detector switches and calibrate all associated instrumentation. The platform prover was drained, flushed with water and the sphere removed for inspection and sizing. It has been found best to bed the sphere in by using it for a week or two prior to the master proof and allow it to assume the usual, slightly elipsoid, shape. The sizing should be about 2-3% over the bore of the prover for large provers such as Piper (24") and Claymore (18").

The most sensitive measurements required for determination of liquid coefficients are the various temperatures at the platform and compact provers. Observation errors in reading glass thermometers are a major source of measurement uncertainty so these were used initially to check the accuracy of the platform instrumentation whose direct digital readout was used thereafter. Intercomparison of the various standard glass thermometers to be used was also carefully carried out to minimise any small offsets to liquid characteristics measured at the different points. Pressure and temperature correction factors for the liquid in use cancel out in the calculations of prover volume when conditions are the same at the master prover, meter and platform prover. It should be noted that differences in conditions between the various points in the system are far more critical than the magnitude of their values. The actual values are however required for calculations of the steel correction factors back to standard (base) conditions. As a rough guide, the liquid temperature coefficients of cubical expansion are 25-30 times those of steel; ie: a 0.1°C temperature difference error between two liquid measurement points has the same effect as a 2.5°C error in the true temperature reading. Similarly, with pressure measurements, the ratio of coefficients is around 5:1 (liquid to steel) for the Piper and Claymore provers. Repeatability and readability are thus of great importance.

DEVELOPMENT OF THE NEW MASTER PROOF METHOD

For the initial proof trial on the Piper platform the procedure shown in Table 1 was to be adopted. The traceability advantages of this method have been fully described by Inglis[4].

This in line with the normal pipe master prover procedure except that the water draw data for obtaining the pipe prover pre-proof volume will have been determined onshore anything up to a year previously and no post-proof water draw would be carried out. It should also be noted that the commercial pipe-prover calibration rigs employ positive displacement meters rather than turbines as the reference device. For master proving with the compact unit, the positive displacement meter is unsuitable due to its inadequate resolution, though its short-term repeatability is superior, particularly under varying flowrate conditions.

Five water draws were obtained within the necessary 0.02% spread, followed by five pre-proof turbine meter calibration runs (each consisting of the mean factor from five compact prover passes) using the same data spread criterion. Master proving then commenced and extreme difficulty was experienced in trying to achieve the five consecutive proof runs within 0.02% spread. 0.1% was being achieved with ease but the platform prover volume results jumped in steps within this band after a few readings. Whilst continuing to calibrate the platform prover, some compact prover runs were then made against the reference meter to track its meter factor and to confirm that the two provers would run in series without unwanted interactions. Similar order jumps in meter factor to those in platform prover pulse counts were noted. The reference meter was taken out of the line and stripped - only to discover that it spun freely on perfect bearings, was clean and that all was well with the pickups and associated electronics.

Pressures and temperatures had remained substantially steady over the course of the proving, so that the changes in meter factor could only be attributed to changes in flowrate and perhaps the float characteristics of the rotor on its liquid bearing. Small slugs of water were also suspected as possibly having settled out in the prover and, being of significantly different viscosity, temporarily altering the meter factor.

By taking the ratio of the meter factor during each platform prover half-trip run and the associated proof pulse count readings, a remarkably good repeatability emerged. Why not, then, discard previous practice and develop a new method? Indeed, there were some obvious advantages in carrying out as many compact prover runs as possible against the reference meter whilst the master proof of the platform prover was ongoing. On Piper, fifteen calibration runs were found possible for each half-trip of the platform prover, the dead time between runs being that taken for the compact prover piston to return. This resulted in a calibration run of approximately three seconds every sixteen seconds evenly spread over the four minute half-trip time. In addition, the meter liquid temperature and pressure corrections totally cancelled out in the calculations of platform prover volume, the recording of meter pressure and temperature readings being retained more by convention than necessity in order to arrive at a meter factor related to base conditions. Five consecutive round-trips within the necessary 0.02% spread were readily obtained using this technique.

The final water draw obtained, though it was observed that it had shifted somewhat and was only just within tolerance. The revised procedure had thus evolved as shown in Table 2.

CALCULATION PRINCIPLES

At an early stage, in considering the use of the compact prover, the need for quickly and accurately carrying out all the necessary prover pressure and temperature correction calculations had been appreciated. In addition, calculations for the water draw had to be completed rapidly in order to assess their validity. A suite of programs had been written for the Hewlett-Packard HP41CV hand-held calculator and printer so that the readings could be keyed in at the master prover location, all the necessary calculations performed, and a printed record retained. This facility proved invaluable in executing the revised procedure since it was useful to calculate the meter factor and the half-trip volume of the platform prover during the four minutes taken by the following run.

This made an immediate accurate judgement of the spread of corrected volumes possible which might otherwise have been difficult if a small (e.g. 0.2°C) temperature change between the provers occurred.

It is important to note that the published tables so often used for both liquid and steel corrections to and from base conditions do not really have adequate resolution for master proving. Thus all correction factors calculated by the program were stored and manipulated to full calculator (12 digit) accuracy and only rounded once the half-trip volume had been determined. Rounding at each stage of correction factor determination or using tables can readily introduce 0.01% glitches in the results - half the allowable result spread.

Since pressure and temperature characteristics of live crudes are not covered by published tables, samples of the platform oils were submitted to a laboratory for PVT analysis to determine their temperature coefficient of cubical expansion and compressibility. These data were used by the calculator program to calculate the liquid corrections. It is necessary to ensure that these coefficients are determined close to the expected proving conditions and that they are also subsequently used in making any liquid corrections required during the routine platform meter proofs.

FURTHER TRIALS

On completion of the Piper master proof the compact prover was shipped to Claymore. The large shift between pre and post water draw results had led to additional checks on piston seal leakage being made, though all appeared to be within the manufacturer's tolerances. Generally the history of this compact prover had always shown extremely repeatable water draw results, with changes in the prover swept volume of the order of 0.01% over a period of months. The reason for the shift on Piper became all too evident when, on Claymore, difficulty in obtaining repeatability on the compact unit prompted the calibration team to strip out the piston and examine the cylinder bore. What appeared to be a line of crevice corrosion had affected the honed bore along the bottom of the cylinder for a considerable length. The gap through which liquid could bypass the piston was estimated to be about 1-2 mm^2 and the piston seals had suffered somewhat by contact with the resultant rough edge. The leak checks had been carried out, by chance, in an area of the bore virtually undamaged and had thus not revealed any problems.

In due course a new cylinder was obtained and seals replaced, with the lesson learnt to check for leakage at several points along the length of the swept volume and preferably also visually inspect the cylinder bore! Both these checks were simple to perform. It was noteworthy that the great sensitivity of the water draw procedure had highlighted the problem. In view of the doubts over the first trial proof which had been performed on Piper, it was repeated. The resulting platform prover volume came very close to the first and demonstrated that such calibration of the compact prover against water draws compensated even for such severe damage to the bore.

The calibration of the four volume combinations of Claymore's prover was achieved with better repeatability and speed than ever before. The greater flowrate capability of the compact unit also reduced the temperature drops between the platform and master provers by a factor of two compared with the previous portable pipe provers used, thus significantly improving one of the greatest sources of measurement uncertainty.

A year on - the Piper platform prover volume was again calibrated against the same compact prover. The difference between the 1983 and 1984 calibrations was 0.007%. Typical calibration sheets showing the calculations and results are appended. A number of improvements were made over the year to the compact prover to facilitate easier checking of piston leakage rates and protect against entry of foreign objects which might damage the cylinder bore or piston seals. Resolution and intra-rotational linearity of the reference turbine meter was improved by fitting a rimmed rotor in place of the blade type used in the first trials.

SUMMARY

The compact prover, despite early tribulations, has been demonstrated to perform an admirable job and the perserverance in developing new operating methods has resulted in improved performance as a master prover. The characteristics of the reference meter can largely be ignored and, by in situ water drawing, so can the long-term repeatability of the compact prover. The results using the revised operating procedure described have been accepted by the fiscal authorites.

The use of a compact prover as a permanent offshore calibration standard for routine meter proving will be considered by many as desirable for the lightweight jacket and floating production systems being proposed for marginal fields. Experience gained in use as a master prover has been invaluable in assessing the compact prover's suitability for such service.

ACKNOWLEDGEMENTS

The author wishes to thank the Piper and Claymore operations and maintenance staff, Mr. Gerry Inglis of Caleb Brett Technical Services and Mr. Bruce Lawson of ICE Petrochemical Engineering Ltd. for their cooperation and considerable assistance during the trials.

REFERENCES

1. "API Manual of Petroleum Measurement Standards - Chapter 4 Proving Systems". API, May 1978 and 1983 Draft Rev.

2. Wolf, R.J. "Meter Proving with the compact piston prover". Proc. Inst. M.C. Conf. Aberdeen 1983 - Flow Metering and Proving Techniques in the Offshore Industry.

3. Brooks Instrument Div., Emerson Electric Co., Statesboro, Georgia. Technical Literature.

4. Inglis, G.E. "The Application and Operation of Compact Provers as used for the recalibration of in-service Mechanical Displacement Piper Provers Offshore" Proc. Inst. M.C. Conf, Aberdeen 1983 - Flow Metering and Proving Techniques in the Offshore Industry.

TABLE 1
CONVENTIONAL MASTER PROVING PROCEDURE

1. Water draw compact prover on site
2. Calculate pre-proof compact prover volume
3. Calibrate reference turbine
4. Obtain pre-proof turbine meter factor
5. Calibrate platform prover against reference meter
6. Calibrate reference turbine (post-proof)
7. Obtain post-proof meter factor
8. Water draw compact prover on site
9. Calculate post-proof compact prover volume
10. Calculate mean compact prover volume and recalculate steps 3/4, 6/7 and 5.

TABLE 2
REVISED MASTER PROVING PROCEDURE

1. Water draw compact prover
2. Calculate pre-proof compact prover volume
3. Calibrate platform prover against reference meter. Reference meter factor separately determined against compact prover for each half trip of platform prover.
4. Water draw compact prover
5. Calculate post-proof compact prover volume
6. Calculate mean compact prover volume and recalculate step 3

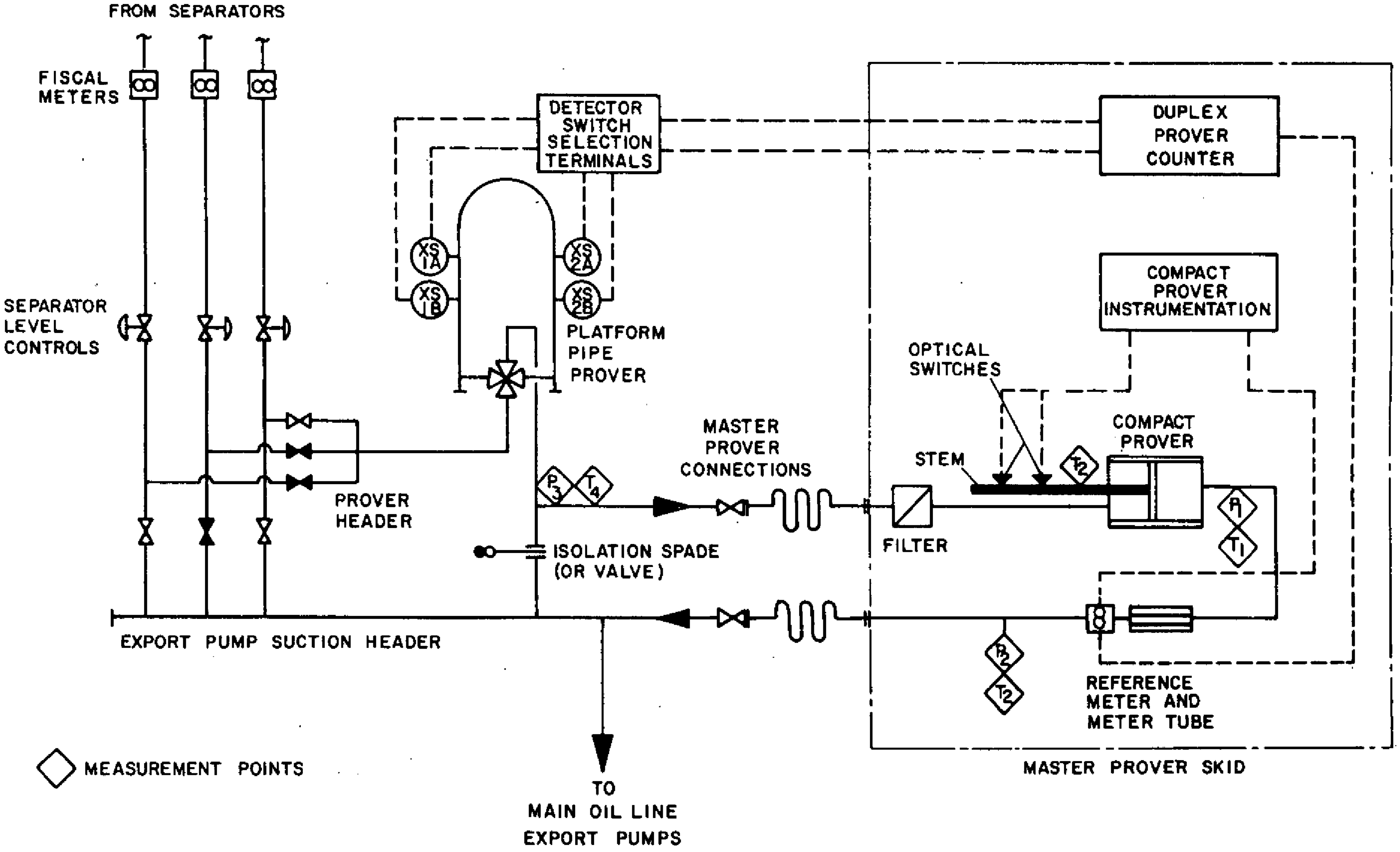

FIG.1. TYPICAL HOOK-UP SCHEMATIC FOR MASTER PROVING

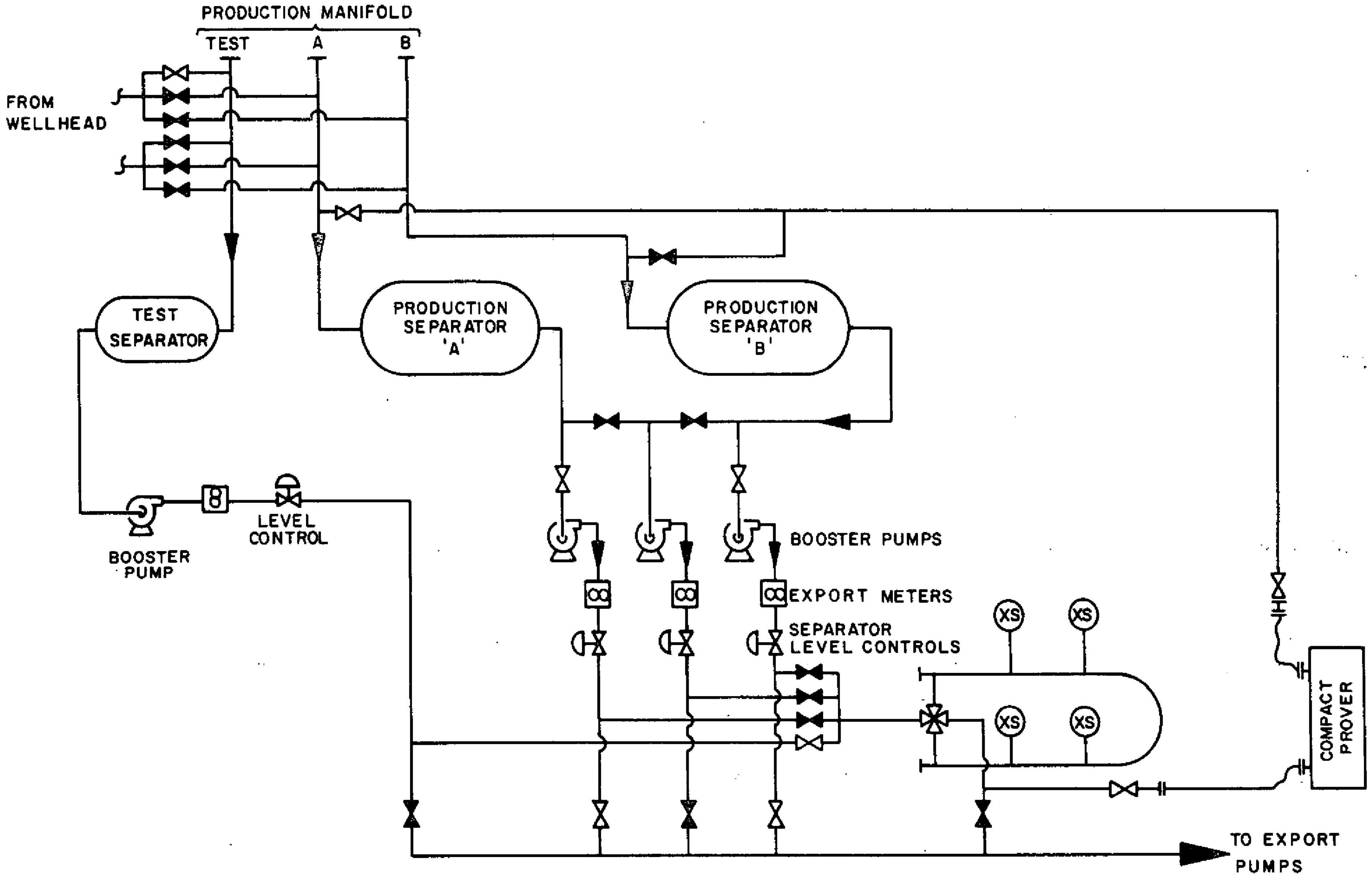

FIG. 2. CRUDE ROUTING FOR MASTER PROVING — CLAYMORE

Caleb Brett Technical Services

CALIBRATION REPORT for
COMPACT METER PROVER (BY WATER DRAW)

PRE-CALIBRATION
WATER DRAW

Page 1 of 2

CLIENT OCCIDENTAL PETROLEUM
LOCATION PIPER ALPHA PLATFORM
DATE 29th AUGUST, 1984.

PROVER SERIAL No. 8202-08841
MANUFACTURER BROOKS INSTRUMENT
NOMINAL INT. DIA. (D) 12.25"
WALL THICKNESS (t) 0.875"

PROVING TANK SERIAL No. 10031-3
CERTIFYING AUTHORITY NATIONAL WEIGHTS & MEASURES LABORATORY
DATE OF CERTIFICATION 20th JANUARY 1984
VOLUME 56.7298 S.I. LITRES (3461.8648 IN^3) @ 15°C.

RUN No. (1)	MEASURE LITRES BASE VOLUME (2)	SCALE RGD. IN^3 (3) +	SCALE RGD. IN^3 (3) -	READ VOLUME @ T_3 (4)	TEMPERATURE (°C.) CP T_1 (5)	ST T_2 (6)	MEAS. T_3 (7)	Δ T $T_1 - T_3$ (8)	PRESSURE PROVER (BAR G) P_1 (9)	TEMPERATURE CORRECTION CTL (10)	CTSm (11)	CTSp (12)	PROVER VOLUME AT P_1 & REF. TEMP. (4) x (10) x (11) x (12) (13)
A2	56.7298	17.0		57.0084	18.2	15.7	18.0	0.2	3.3	1.00004	1.00014	0.99993	57.0147
A3	56.7298	17.0		57.0084	18.3	16.0	18.1	0.2	3.5	1.00004	1.00015	0.99992	57.0147
A4	56.7298	17.0		57.0084	18.4	16.2	18.2	0.2	3.4	1.00004	1.00015	0.99992	57.0147
A5	56.7298	16.5		57.0002	18.5	16.0	18.2	0.3	3.4	1.00005	1.00015	0.99992	57.0069
A6	56.7298	16.7		57.0035	18.4	15.9	18.1	0.3	3.4	1.00005	1.00015	0.99992	57.0103
											SPREAD	= 0.014%	

VOLUME LITRES
REF. TEMP. (T) 15°C.
REF. PRESSURE (P) 0 BAR G

AVERAGE DISPLACED VOLUME AT P_1 & REF. TEMPERATURE
= 57.0123 (14)

PRESSURE CORRECTION FACTORS
CPL 0.99984 (15)
CPS 0.99998 (16)

∴ AVERAGE DISPLACED VOLUME AT REFERENCE TEMPERATURE & ATMOSPHERIC PRESSURE,
= (14) x (15) x (16)
= 57.0020 S.I. LITRES

NOTES ALL REFERENCES FROM MANUAL OF PETROLEUM MEASUREMENT STANDARDS/TABLES.

COLUMN (5)(6)(7) TEMPERATURES SHOWN ARE CORRECTED READINGS

COLUMN				
(10)	THERMAL EXPANSION WATER	: CHAPTER 11.4.2.		
(11)	THERMAL EXPANSION STEEL (MEASURE)	: CHAPTER 12.2. PARA 12.2.5.1.	$1 + (T_3 - T)(\gamma)$	WHERE γ = 0.0000477/$^\circ$C.
(12)	THERMAL EXPANSION STEEL (PROVER)	: CHAPTER 12.2. PARA 12.2.5.1.	$1 - [(T_1 - T)(\gamma_1) + (T_2 - T)(\gamma_2)]$	WHERE γ_1 = 0.0000223/$^\circ$C. γ_2 = 0.0000016/$^\circ$C.
(15)	COMPRESSIBILITY OF WATER	: CHAPTER 12.2. PARA 12.2.5.4.	$1 \div [1 + (P_1 - P)(F)]$	WHERE F = 0.0000464/BAR
(16)	EXPANSION OF STEEL-PRESSURE	: CHAPTER 12.2. PARA 12.2.5.2.	$1 - (P_1 D/Et)$.	WHERE E = 2.0 x 10^6

ENGINEER

P. EVANS/P. BOYLE

ISSUED BY

G.E. INGLIS
For and on behalf of Caleb Brett Technical Services

FLME 008/8/83

Caleb Brett Technical Services

CALIBRATION REPORT for
COMPACT METER PROVER (BY WATER DRAW)

POST CALIBRATION
WATER DRAW

Page 2 of 2

CLIENT OCCIDENTAL PETROLEUM
LOCATION PIPER ALPHA PLATFORM
DATE 2nd SEPTEMBER 1984.

PROVER SERIAL No. 8202-08841
MANUFACTURER BROOKS INSTRUMENT
NOMINAL INT. DIA. (D) 12.25"
WALL THICKNESS (t) 0.875"

PROVING TANK SERIAL No. 10031-3
CERTIFYING AUTHORITY NATIONAL WEIGHTS & MEASURES LABORATORY
DATE OF CERTIFICATION 20th JANUARY 1984
VOLUME 56.7298 S.I. LITRES (3461.8648 IN^3) @ 15°C.

RUN No.	MEASURE LITRES				TEMPERATURE (°C.)				PRESSURE PROVER (BAR G)	TEMPERATURE CORRECTION			PROVER VOLUME AT P_1 & REF. TEMP.
	BASE VOLUME	SCALE RGD. IN^3		READ VOLUME @ T_3	CP T_1	ST T_2	MEAS. T_3	Δ T $T_1 - T_3$	P_1	CTL	CTSm	CTSp	(4) x (10) x (11) x (12)
		+	-										
(1)	(2)	(3)		(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
B1	56.7298	16.9		57.0067	20.5	24.4	20.8	-0.3	3.5	0.99993	1.00028	0.99986	57.0107
B2	56.7298	16.6		57.0018	20.7	25.2	20.7	NIL	3.5	1.00000	1.00027	0.99986	57.0092
B3	56.7298	17.0		57.0084	20.4	24.7	20.7	-0.3	3.5	0.99993	1.00027	0.99986	57.0118
B4	56.7298	17.0		57.0084	20.4	21.2	20.6	-0.2	3.5	0.99995	1.00027	0.99987	57.0135
B5	56.7298	16.7		57.0035	20.5	22.0	20.5	NIL	3.5	1.00000	1.00026	0.99987	57.0109
											SPREAD	= 0.008%	
										AVERAGE	(Pre-post)	VOLUME	=
												57.0015 LITRES	
										SPREAD	(Pre-post)	= 0.002%	

VOLUME LITRES
REF. TEMP. (T) 15°C.
REF. PRESSURE (P) 0 BAR G.

AVERAGE DISPLACED VOLUME
AT P_1 & REF. TEMPERATURE
= 57.0112 (14)

PRESSURE CORRECTION FACTORS
CPL 0.99984 (15)
CPS 0.99998 (16)

∴ AVERAGE DISPLACED VOLUME
AT REFERENCE TEMPERATURE &
ATMOSPHERIC PRESSURE.
= (14) x (15) x (16)
= 57.0009 S.I. LITRES

ENGINEER
P. EVANS/P. BOYLE

ISSUED BY
G E Inglis
G.E. INGLIS
For and on behalf of Caleb Brett Technical Services

NOTES ALL REFERENCES FROM MANUAL OF PETROLEUM MEASUREMENT STANDARDS/TABLES.
COLUMN (5)(6)(7) TEMPERATURES SHOWN ARE CORRECTED READINGS

(10)	THERMAL EXPANSION WATER	: CHAPTER 11.4.2.			
(11)	THERMAL EXPANSION STEEL (MEASURE)	: CHAPTER 12.2. PARA 12.2.5.1.	$1 + (T_3 - T)(\gamma)$	WHERE γ =	0.0000477/°C.
(12)	THERMAL EXPANSION STEEL (PROVER)	: CHAPTER 12.2. PARA 12.2.5.1.	$1 - [(T_1 - T)(\gamma_1) + (T_2 - T)(\gamma_2)]$	WHERE γ_1 =	0.0000223/°C.
				γ_2 =	0.0000016/°C.
(15)	COMPRESSIBILITY OF WATER	: CHAPTER 12.2. PARA 12.2.5.4.	$1 - [1 + (P_1 - P)(F)]$	WHERE F =	0.0000464/BAR
(16)	EXPANSION OF STEEL - PRESSURE	: CHAPTER 12.2. PARA 12.2.5.2.	$1 - (P_1 D/Et)$	WHERE E =	2.0×10^6

LME 008/8/83

Page 1 of 1

Caleb Brett Technical Services

CALIBRATION REPORT for MECHANICAL DISPLACEMENT METER PROVER (BY REFERENCE METER/ COMPACT PROVER)

CLIENT OCCIDENTAL PETROLEUM
LOCATION PIPER 'ALPHA' PLATFORM
DATE 2nd SEPTEMBER 1984.

PROVER SERIAL No PIPER 'ALPHA' PROVER
MANUFACTURER A.O.T.
TYPE 24" NB BI-DIRECTIONAL

RUN No (1)	CP VOLUME FACTOR or PULSE COUNTS (2)	K-FACTOR or K-GROSS (3)	TEMPERATURE °C. CP T_1 (4)	ST T_2 (5)	M T_3 (6)	PP T_4 (7)	PRESSURE BAR CP P_1 (8)	M P_2 (9)	PP P_3 (10)	CORRECTION FACTORS CP or PP CTSp (11)	CPSp (12)	CP or PP CTLp (13)	CPLp (14)	METER CTLm (15)	CPLm (16)	K-GROSS or PROVER VOLUME (17)	AVERAGE K-GROSS or TOTAL VOLUME (18)
30F	0.99997	13.3064	57.8	22.8	57.8		15.2	15.0		1.00097	1.00011	0.95574	1.00184	0.95574	1.00182	13.29138	
	59392	13.29138			57.8	58.1		15.0	18.3	1.00144	1.00042	0.95543	1.00221	0.95574	1.00182	4459.8724	
30R	0.99997	13.3040	57.8	22.8	57.8		15.2	15.0		1.00097	1.00011	0.95574	1.00184	0.95574	1.00182	13.28898	
	59327	13.28898			57.8	58.1		15.0	18.3	1.00144	1.00042	0.95543	1.00221	0.95574	1.00182	4455.7960	8915.6684
31F	0.99997	13.3135	57.6	21.2	57.6		15.0	14.7		1.00096	1.00011	0.95595	1.00182	0.95595	1.00178	13.29834	
	59407	13.29834			57.6	57.9		14.7	17.4	1.00144	1.00040	0.95564	1.00211	0.95595	1.00178	4459.0197	
31R	0.99997	13.3137	57.4	25.2	57.4		15.0	14.7		1.00096	1.00011	0.95616	1.00182	0.95616	1.00178	13.29854	
	59370	13.29854			57.4	57.7		14.7	17.4	1.00143	1.00040	0.95585	1.00211	0.95616	1.00178	4456.2197	8915.2394
32F	0.99997	13.3141	57.3	26.0	57.3		15.0	14.7		1.00096	1.00011	0.95626	1.00182	0.95626	1.00178	13.29894	
	59409	13.29894			57.3	57.6		14.7	17.4	1.00143	1.00040	0.95595	1.00211	0.95626	1.00178	4459.0127	
32R	0.99997	13.3082	57.2	25.8	57.2		15.0	14.7		1.00096	1.00011	0.95637	1.00182	0.95637	1.00178	13.29304	
	59352	13.29304			57.2	57.5		14.7	17.4	1.00142	1.00040	0.95606	1.00211	0.95637	1.00178	4456.7560	8915.7687
33F	0.99997	13.3083	57.2	23.8	57.2		15.0	14.7		1.00096	1.00011	0.95637	1.00182	0.95637	1.00178	13.29314	
	59400	13.29314			57.2	57.5		14.7	17.4	1.00142	1.00040	0.95606	1.00211	0.95637	1.00178	4460.3268	
33R	0.99997	13.3086	57.2	23.7	57.2		15.0	14.7		1.00096	1.00011	0.95637	1.00182	0.95637	1.00178	13.29344	
	59345	13.29344			57.2	57.5		14.7	17.4	1.00142	1.00040	0.95606	1.00211	0.95637	1.00178	4456.0963	8916.4231
34F	0.99997	13.3077	57.2	24.8	57.2		15.0	14.7		1.00096	1.00011	0.95637	1.00182	0.95637	1.00178	13.29254	
	59396	13.29254			57.2	57.5		14.7	17.4	1.00142	1.00040	0.95606	1.00211	0.95637	1.00178	4460.2278	
34R	0.99997	13.3135	57.2	24.8	57.2		15.0	14.7		1.00096	1.00011	0.95637	1.00182	0.95637	1.00178	13.29834	
	59357	13.29834			57.2	57.5		14.7	17.4	1.00142	1.00040	0.95606	1.00211	0.95637	1.00178	4455.3551	8915.5829
															SPREAD	= 0.014%	

UNIT VOL LITRES
REF TEMP (T) 15°C.
REF PRESSURE (P) 0 BAR G

FLOWRATE 950/1125 LPM
PRODUCT CRUDE OIL
TEMP.COEF. = 1034×10^{-6}/°C.
PRES.COEF. = 121×10^{-6}/BAR

PIPE PROVER NOM I D (D) 23.000"
WALL THICKNESS (t) 0.500"
SPHERE DIA 23.600"
SPHERE MATL NEOPRENE

COMPACT PROVER NOM I D (D) 12.25"
WALL THICKNESS (t) 0.875"
BASE VOLUME 57.0015 LITRES
SET-IN VOLUME 57.0000 LITRES

REFERENCE METER DANIEL
SERIAL No. 82-00802
SIZE/TYPE 3" TURBINE

CP – COMPACT PROVER
ST – SENSOR TUBE of CP
PP – PIPE PROVER
M – REFERENCE METER

NOTES ALL REFERENCES FROM MANUAL OF PETROLEUM MEASUREMENT STANDARDS/TABLES.

COLUMN (2) CP VOLUME FACTOR = SET-IN VOLUME (COUNTER) ÷ BASE VOLUME (WATER DRAW)
(3) K-FACTOR OBTAINED FROM PRINT-OUT. K-GROSS OBTAINED FROM AVERAGE K-FACTORS
(4)(5)(6)(7) TEMPERATURES SHOWN ARE CORRECTED READINGS
(11) THERMAL EXPANSION OF STEEL : CHAPTER 12.2. PARA 12.2.5.1
(12) EXPANSION OF STEEL - PRESSURE CHAPTER 12.2. PARA 12.2.5.2
(13)(15) THERMAL EXPANSION OF PRODUCT ~~ASTM 1250 - 80~~
(14)(16) COMPRESSIBILITY OF PRODUCT ~~CHAPTER 11.2~~

$CP = 1 + (T_1 - T)(\gamma_1) + (T_2 - T)(\gamma_2)$ WHERE γ_1 = 0.0000223/°C.
γ_2 = 0.0000016/°C.
$PP = 1 + (T_4 - T)(\gamma)$ WHERE γ = 0.0000335/°C.
$CP = 1 + (P_1 D/Et)$ WHERE E = 2.0×10^6
$PP = 1 + (P_3 D/Et)$ WHERE E = 2.0×10^6

$CPL_{cp} = 1 - [1 - (P_1 - P)(F)]$ WHERE F =
$CPL_{pp} = 1 - [1 - (P_3 - P)(F)]$ WHERE F =
$CPL_m = 1 - [1 - (P_2 - P)(F)]$ WHERE F =
SEE TEMP.+ PRESS. COEFFICIENTS ABOVE.

(17) K-GROSS AT REF. TEMP/ATMOS PRESSURE

$$= \frac{\text{K-FACTOR} \times \text{CPVF} \times \text{CTLm} \times \text{CPLm}}{\text{CTSp} \times \text{CPSp} \times \text{CTLp} \times \text{CPLp}}$$

$$= \frac{2 \times 3 \times 15 \times 16}{11 \times 12 \times 13 \times 14}$$

(18) PIPE PROVER VOLUME AT REF. TEMP/ATMOS PRESSURE

$$= \frac{\text{PULSE COUNTS} \times \text{CTLm} \times \text{CPLm}}{\text{K-GROSS} \times \text{CTSp} \times \text{CPSp} \times \text{CTLp} \times \text{CPLp}}$$

$$= \frac{2 \times 15 \times 16}{3 \times 11 \times 12 \times 13 \times 14}$$

AVERAGE DISPLACED ROUND TRIP VOLUME AT REFERENCE TEMPERATURE & ATMOSPHERIC PRESSURE
= 8915.7365 S.I. LITRES

ENGINEER
P. EVANS/P. BOYLE

ISSUED BY
G.E. INGLIS
For and on behalf of Caleb Brett Technical Services