COMPARISON TEST AND CALIBRATION OF CORIOLIS METERS

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SUMMARY

Coriolis Mass Meters are just as accurate and linear as many Turbine Meters. They should be calibrated under the same conditions as they are to be operated at otherwise metering errors of up to 3% can be experienced. The meters zero stability are good and not influenced by increasing pressures or temperatures. They also show a small viscosity dependent effect on readings.

If a Coriolis Meter is operated at elevated pressures and temperatures, the density output option should be used with great care.

Verification with the manufacturer of the fluid density used when stating meter throughput or pressure drop versus flowrate is recommended

1.0 BACKGROUND

In 1992 Con-Tech was approached by Statoil a/s with a request for our interest to participate in an evaluation test of Coriolis Meters. The purpose of the testing was to evaluate the meters under simulated process conditions similar to those experienced offshore. Of particular interest was the region common to an allocation metering and test separator metering environment, those of high temperature and high pressure.
As those test were not available at the that time, a purpose built calibration facility was required.

The resulting specifications for the calibration facility became as follows:

Hydrocarbons to be used as calibration liquids
Multiple storage tanks for various qualities of hydrocarbon liquids
0 - 400 m^3 / hour as range of flowrates
0 - 95 barg pressure range
20 - 85 °C temperature range
3 parallel meter streams
2 by-pass type densitometers in parallel
Multiple pressure and temperature transmitters
Real time data acquisition and computations
Resemblance to a offshore metering station was desired
Due to the use of hydrocarbons all electrical equipment to be EEx

In summer 1994, following the completion of a 10 month test program, the calibration facility became commercially available for calibration of any liquid flow meters, volume or mass.

2.0 CALIBRATION SET-UP

The calibration loop consists of 3 parallel streams connected to an inlet and outlet header (Fig. 1). One stream is 6" pipe and 2 streams are 4" pipe. Each stream has a double block and bleed inlet valve and space for installing a Coriolis Mass Meter (CMM), Turbine Meter, Ultrasonic Meter, Positive Displacement Meter, or any other meter for liquid measurement.

Adjustable points for meter or pipe support, pressure taps before and after the meter under test, pressure and temperature transmitters, location for insertion densitometers and outlet flow control valve are installed. Dual Schlumberger Oil Densitometers, model 7835, are located downstream of the outlet header with one pressure and two temperature transmitters. Further downstream is the takeoff to the heat exchangers with a bypass flow control valve. Next comes a variable speed circulation pump before the liquid enters a Brooks Compact Prover.
The tie-in for liquid filling and pressurisation is also upstream of the pump.

Signals from meters under test, densitometers, pressure and temperature transmitters are all connected to a Siemens Sicomp process machine (Fig. 2). This machine, with its installed calculation algorithms, is similar to machines used on offshore platforms for fiscal flow measurement. Temperatures and pressures on the Compact Prover are routed to its Computer, for display and printout.

The VDU presentation consists of, for every stream; temperature, pressure, volumetric flow rate, mass flow rate from a CMM, calculated mass flow rate from reference if a comparison test is ongoing, density , density meter temperature and pressure.

The process machine software also has a feature for data sampling and averaging, sampling time selectable by operator. Accumulated mass and volume, measured and calculated from reference, during the sampling period are also displayed.

All data collected during a sampling period can be transferred to our PC for presentation in engineering units. This data file is transferred to a calculation program, developed by Con-Tech, and any manually logged data is also entered here.

This calculation program converts Compact Prover volume, volume displaced during meter calibration and density to the conditions at the turbine meter. Hence the calculated accumulated mass or mass flowrate is at turbine meter conditions and this data is compared to the accumulated mass or mass flowrate from the CMM under test. The density output from the CMM is also compared to our reference densitometers, with this density calculated to Coriolis meter conditions.

As an extra verification of the density, an oil sample is drawn during a test and sent to an independent laboratory for density and also viscosity determination.

Coefficients for the oil's thermal expansion and compressibility are determined by varying temperature and pressure and then calculating density changes per °C and barg. This is done in the range where the calibration is performed.

3.0 CALIBRATION PROGRAM

The large calibration program, with 6 different CMM's, to be performed for Statoil a/s, was set up to be a 5 point calibration over the meters said range; or the range achieved with a maximum of 1,5 bar differential pressure over the meter and with the following pressure and temperature conditions:

20 °C, 60 °C 85 °C 10 barg, 70 barg 95 barg

Calibration liquids to be water, 3 crude oils with density range 0,83 to 0,89 kg/l and viscosity range 5 to 19 cSt, and naphtha with density 0,65 kg/l and viscosity 0,6 cSt.

In addition the following criteria's were to be adhered to:

- Calibration on every rate and condition should be repeated 3 times.
- Calibration data should be collected for at least 3 minutes.
- The master meter should be calibrated every time the conditions changed, with 5 runs of 5 passes on the Compact Prover, and a spread of the 5 runs to be better than 0,05%.
- Temperature stability during a test to be within ± 0,2 °C.
- Zero flow to be recorded for every change in pressure/temperature, but not adjusted.
- Density and temperature readout from the CMM to be recorded and compared with reference.

This calibration matrix gave a total of 4050 data points to collect and a minimum of 33750 single calibrations of the master meters, 2" and 3" Brooks Parity High Resolution Turbine Meters.

Following discussions with Statoil a/s it was decided that the CMM's to be tested would be:

ABB Kent-Taylor	K-Flow K-2500	2"
Endress+Hauser	M-Point DQ 600	3"
Exac Corporation	Exac EX 3000 H	3"
Foxboro Company	Foxboro CFS 10	2"
Micro Motion Inc	Elite CMF 300 M	3"
Schlumberger	Massmaster 150	2"

Due to start-up delays it was decided to omit one of the crude oils from the test program. Also, due to various circumstances, three meters were not tested through the full program. (Table 1.)

The final calibration program became as follow: (meters in random order)

Table 1.

METER NO:	WATER 1 kg/l 1 cSt	NAPHTHA 0,65kg/l 0,6 cSt	CRUDE OIL 0,84 kg/l 7 cSt	CRUDE OIL 0,89kg/l 19 cSt
A				
B				
C				
D				
E				
F				

4.0 PROCEDURE

The various CMM's were installed and supported in strict accordance with the manufacturers recommendations. The CMM's flow computer were configured by vendor representatives and the complete installation were accepted by the vendor in writing.

The initial calibrations on each CMM were to be on water at 20 °C and 10 bar in order to compare this calibration with the factory calibration and thus have an indication of a healthy meter and calibration set-up.

By monitoring the pressure drop whilst increasing flow rate, the maximum flow rate was found, and the meter was calibrated on the 3 highest points. After some number crunching the data was compared with the reference and if they were within ± 0,2 % of the factory calibration, the factory K-factor was not changed and the rest of the curve completed.

In order to compare the result from the CMM with the result from the reference a special calculation program was developed. Process data and flow data was averaged and accumulated during the sampling period by the Sicomp Process Machine. The sampling period was set to 3 minutes so that one pulse lost would have a influence in the final result of 0,002% or less. For the low rate on 2" meters the sampling time was 5 minutes.

The turbine meter was calibrated after any change in flowing conditions by using the Compact Prover. The procedure was 5 passes per run and 5 runs, with a repeatability better than 0,05%. The meter factor was corrected to turbine meter conditions, hence recalculating the prover volume also to turbine meter conditions.
This meter factor was entered into the Process Machine and the sampling period started. After completion the collected data was transferred to a data file and a new sampling period started. A third sampling period was also performed with the repeatability of CMM and reference monitored.

5.0 CALIBRATION RESULTS

5.1 General.

The detailed calibration results belong to our client but we are allowed to present results in a general manner. The results and comments are not connected to any particular manufacturer.

5.2 Pressure Drop

The pressure drop results obtained from various meters on various fluids are detailed in Table 2.
We experienced some problems in achieving the maximum flowrate at the maximum test programme pressure drop (1.5 bar). One manufacturer claimed they have used a liquid density of 1,5 kg/l in order to achieve the maximum mass flowrate.

Some of the results to note are:

- Meter C on water with a pressure drop of 0.8 bar at 140 tonnes per hour (tph). The manufacturers literature quotes 3.1 bar at 272 tph.
- Meter F on water with a pressure drop of 1.5 bar at 50 tph. The manufacturers literature quotes 0.7 bar at 42 tph.

- Meter D on water with a pressure drop of 1.5 bar at 40 tph
  The manufacturers literature quotes 2.45 bar at 68 tph.

5.3 Temperature Reading

The coriolis mass meter temperature read out results compared to the reference temperature instrument are published in Table 3. Results from the coriolis meters ranged from 0 up to 2.5°C differences from the reference, the highest vaiances not considered as acceptable for fiscal or custody transfer purposes.

5.4 Density Reading

The coriolis mass meter density readings at various temperatures and pressure were noted on the various test fluids and compared to the reference density meters. The results are published in Tables 4 to 7.

All the meters tested showed either some pressure dependence, temperature dependence or a combination of both when the results were compared to the reference instruments.
In general, the results over the test fluid parameter ranges do not conform to what is " normally " acceptable for custody transfer or fiscal metering standard instruments.

5.5 Coriolis Mass Meters

5.5.1 Meter Zero

When checking zero-flow the procedure was to close valves both upstream and downstream of the meter. All meters were zeroed at the initial water calibration and they did not require to be re-zeroed during the test, even at the highest pressure and temperature combination. The zero-flow indication varied between -0,2 to 0,5 ton/hour and the indication for most of the meters varied in an unsystematic way. For one of the meters we experienced a substantial increase in flow indication when the downstream butterfly valve was closed. This gave indication of sensitivity to frequency reflection and feedback.

Table 8. shows the zero error readings for a number of meters on a variety of fluids over the test pressure and temperature ranges.

5.5.2 Water Calibrations

The initial calibrations were performed on water at 20°C and 10 bars pressure.
Results from the initial water calibrations performed on all the meters are shown in Fig.3. As one can see, meter C and meter F stand out with very good linearity. Only meter D gave results which were positive relative to the reference.
After initial water calibration and consultation with the manufacturer, for one of the meters we changed the manufacturer supplied K-factor by 0,25% .

Next the test pressure was elevated to 95 bars whilst keeping the temperature at 20°C. The results are shown in Fig. 4. Meters B and E were not present for these tests.
Meter A took a drop of 0.5 % at the lowest rates whilst meter C kept the linearity but gave a further 0,75% under registration. The same applies to meter F with a good 1% drop in registration, however it kept its linearity.

Testing was then carried out on the water at 85 °C with 10 bar pressure, results are shown in Fig.5. Meter F still has very good linearity but 0,5% drop in reading. Meter D has improved its linearity and now has a 1% under registration. Meter A likes temperature better than pressure and meter C is now using the fiscal requirement for linearity, ± 0,25%, to its fullest extent.

The meters were then tested over a variety of temperatures and pressure on water. A typical set of results is shown in Fig. 6 which gives results for 5 of the meters on water at 60 °C and 95 bar. If this is your process conditions meter A stands out as the meter to use. Meter C and F are still linear but now 1 - 1,5% down in reading. Meter E also likes these conditions now around the zero line, up from -0,75% at the initial calibration.

Meter F at all water points is shown in Fig.7. This was the most linear meter we found on water. The meter is clearly temperature and pressure sensitive but this can easily be corrected for after a calibration.

5.5.3 Hydrocarbon Calibrations

The CMM's were tested using a variety of crude oils / hydrocarbons and pressure and temperature ranges as on water. The initial viscosity's at 20°C are shown in Table 1

Figs.8 and 13 show all the calibration points for meters F and A on the heavy crude oil. For meter F at elevated temperatures and pressures the excellent linearity has now gone. With meter A most of the points are within a 2% span however its temperature sensitivity on this liquid can be observed. This meter has good linearity if a 4:1 turn down can be accepted.

A comparison between 3 meters on heavy crude is shown in Fig.9. We can observe that meter A performance improves under high temperatures and pressures whilst meter F deteriorates.

A comparison of results for a mid range viscosity crude (0.84 kg/l, 7 cSt) at elevated temperature and pressure is shown in Fig.11. All meters show a significant shift in readings.
For one meter we experienced a 10 % under-registration at 70 bar, and it was claimed that the flow computer corrected for pressure effects. We also tested one other meter of this model with the outcome being similar results.

For the low end viscosity naphtha was used. No results for the high temperature / low pressure ranges were obtained as naphtha is not a single phase fluid in these regions. We observed that our pump cavitation did not end until we were above 50 bar pressure at 85°C.

Fig.10 shows a comparison of results for three meters on naphtha. Linearity has improved on some meters when compared to the heavy crude results, except at the lower flow rates.

In Fig.12 we have plotted all calibration results for meter A when calibrated on naphtha. All points, except 3, are within ±0,5% from the reference.

In general, from the results all meters show a small viscosity dependent effect.

5.5.4 Reference Turbine Meters

For information purposes the calibration results for the turbine meter references used during the CMM calibrations are presented

Fig.14 shows results from the calibration of the 3" turbine on water when meter A was calibrated. For most of the points we find a meter factor between 30,15 and 30,50 pulses per litre, which represents a span of 1,16%! The average meter linearity on 20 °C 10 bar calibrations was ± 0,38% over 10:1 turndown. The average meter repeatability in the various points was 0,015%.

Fig.15 shows results from the calibration of the 2" turbine on water when meter D was calibrated. For all points, less one, we find a meter factor between 48.23 and 48.80 pulses per litre, which represents a span of 1,17%! The average meter linearity on 20 °C 10 bar calibrations was ± 0,23% over 10:1 turndown. The average meter repeatability in the various points was 0,013%. We observed a shift in the meter factor leaving 20 °C but a similar shift in meter D performance was not observed.

Fig.16 plots the meter curves for the 3 hydrocarbon liquids. Sensitivity to viscosity can clearly be observed and also that we achieved better linearity calibrating on naphtha.

Finally fig.17 plots all calibration points for the 3" turbine on the heavy crude. This graph clearly displays the temperature sensitivity, i.e. liquid viscosity. The total range for all these meter factors are 2,35%.

6.0 CONCLUSIONS

All meters were sensitive to pressure and temperature increases. It can be concluded the Coriolis Mass Meter should be calibrated at process conditions in a test facility or the user should install connections and valves and have sufficient space so the meter can be calibrated in-situ.

All meters were, more or less, showing less than actual throughput. The problem is easy to correct during a calibration.

There is a small viscosity effect, the higher the viscosity the higher the error. A positive effect is that lower viscosity improved the meters linearity.

Meter zero was good and not influenced by increasing temperature and pressure.

All of the density outputs from the Coriolis Mass Meter's tested showed some dependence on either temperature or pressure or on both parameters. At elevated temperatures and pressure the density outputs should be used with care as they may not be suitable for custody transfer or fiscal purposes.

Potential users must clarify what conditions/liquids the manufacturer is using as his basis for throughput quotations.

In general the temperature output signals from the meters tested were not considered as suitable for use other than as indication instruments.

TABLE 2. CORIOLIS METER PRESSURE DROP vs FLOW RATE RESULTS

METER	FLUID	FLOW RATE Tonnes/hour	PRESSURE DROP Bar
A	WATER	130	1.0
A	NAPHTHA	92	1.1
A	MEDIUM CRUDE	107	1.5
A	HEAVY CRUDE	104	1.4
C	WATER	140	0.8
C	NAPHTHA	96	0.6
C	MEDIUM CRUDE	110	0.9
C	HEAVY CRUDE	108	0.9
D	WATER	42	1.5
F	WATER	50	1.5
F	NAPHTHA	52	1.5
F	MEDIUM CRUDE	45	1.5
F	HEAVY CRUDE	45	1.5

TABLE 3. CORIOLIS METER TEMPERATURE READ OUT DIFFERENCE FROM REFERENCE READING

METER	FLUID	TEMPERATURE DIFFERENCE °C
A	WATER	-0.2 to +0.2
A	NAPHTHA	-0.2 to -0.4
A	MEDIUM CRUDE	0.0 to -0.6
A	HEAVY CRUDE	0.0
C	WATER	0.0 to -1.5
C	NAPHTHA	-0.2 to -2.2
C	MEDIUM CRUDE	0.0 to -2.5
C	HEAVY CRUDE	-0.1 to -2.2
D	WATER	0.0 to -1.5
F	WATER	-0.2 to -1.0
F	NAPHTHA	-0.25 to -0.7
F	MEDIUM CRUDE	-0.2 to -1.0
F	HEAVY CRUDE	-0.2 to -0.7

TABLE 4. CORIOLIS METER DENSITY READINGS PERCENTAGE DIFFERENCE FROM REFERENCE

METER	FLUID	PRESS.Bars / TEMP °C	20	60	85
A	WATER	10	-0.1	+0.1	+0.4
"	"	70	+1.4	+1.3	+1.5
"	"	95	+1.8	+1.9	+1.9
"	NAPHTHA	10	0.0	+1.1	-
"	"	70	+1.0	+1.7	+2.8
"	"	95	+2.2	+2.5	+2.4
"	MEDIUM CRUDE	10	-0.1	+0.1	+0.5
"	"	70	+1.5	+1.4	+1.9
"	"	95	+2.0	+1.9	+2.4
"	HEAVY CRUDE	10	+0.2	+0.7	+0.1
"	"	70	+1.1	+0.9	+0.9
"	"	95	+1.9	+1.5	+1.5

TABLE 5. CORIOLIS METER DENSITY READINGS PERCENTAGE DIFFERENCE FROM REFERENCE

METER	FLUID	PRESS.Bars / TEMP °C	20	60	85
C	WATER	10	+0.1	-0.3	-0.1
"	"	70	-0.1	-0.3	-0.2
"	"	95	-0.1	-0.2	-0.4
"	NAPHTHA	10	+0.3	+0.9	-
"	"	70	+0.4	+0.8	+1.1
"	"	95	+0.2	+0.7	+1.2
"	MEDIUM CRUDE	10	-0.2	-0.4	-0.6
"	"	70	-0.1	-0.8	-0.7
"	"	95	-0.1	-1.1	-1.6
"	HEAVY CRUDE	10	-0.2	-0.8	-1.3
"	"	70	-0.3	-1.1	-1.3
"	"	95	-0.2	-1.2	-1.3

TABLE 6. CORIOLIS METER DENSITY READINGS PERCENTAGE DIFFERENCE FROM REFERENCE

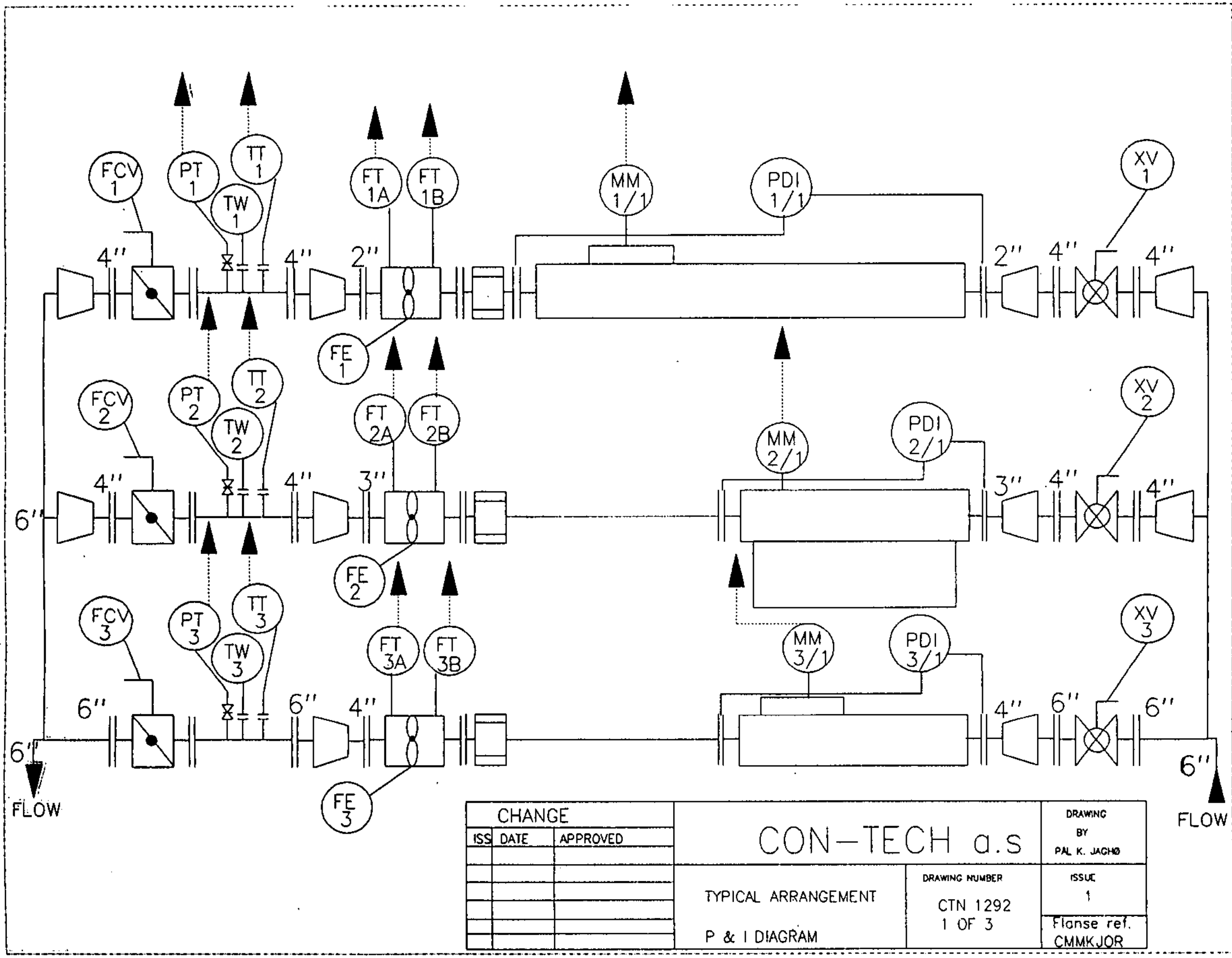
METER	FLUID	PRESS.Bars / TEMP °C	20	60	85
D	WATER	10	+0.1	-0.4	-0.9
"	"	70	-0.6	-1.3	-1.7
"	"	95	-0.7	-1.5	-2.0

TABLE 7. CORIOLIS METER DENSITY READINGS PERCENTAGE DIFFERENCE FROM REFERENCE

METER	FLUID	PRESS.Bars / TEMP °C	20	60	85
F	WATER	10	-0.1	-0.2	+0.1
"	"	70	-1.8	-1.7	-1.7
"	"	95	-2.4	-2.4	-2.3
"	NAPHTHA	10	+0.5	+1.4	-
"	"	70	+2.7	+3.1	+3.3
"	"	95	+3.5	+3.8	+4.3
"	MEDIUM CRUDE	10	-0.6	-1.7	-1.6
"	"	70	-2.5	-2.7	-2.6
"	"	95	-3.0	-3.6	-3.3
"	HEAVY CRUDE	10	-0.6	-1.3	-1.7
"	"	70	-2.2	-3.3	-3.5
"	"	95	-2.9	-4	-4.0

TABLE 8. CORIOLIS MASS METER ZERO ERROR RESULTS

METER	FLUID	ZERO ERROR Tonnes/hour
A	WATER	-0.7 to +0.2
A	NAPHTHA	+0.14 to +0.25
A	MEDIUM CRUDE	-0.2 to +1.0
A	HEAVY CRUDE	-0.1 to +0.54
C	WATER	0.0 to +0.20
C	NAPHTHA	0.0 to +0.26
C	MEDIUM CRUDE	0.0 to +0.24
C	HEAVY CRUDE	0.0 to +0.23
D	WATER	0.0 to +0.10
F	WATER	0.0 to +0.28
F	NAPHTHA	-0.06 to +0.24
F	MEDIUM CRUDE	-0.04 to -0.21
F	HEAVY CRUDE	0.0 to +0.30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TW 1
TT 1
FT 1A
FT 1B
FE 1
MM 1/1
PDI 1/1
XV 1
FCV 2
PT 2
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FT 2A
FT 2B
FE 2
MM 2/1
PDI 2/1
XV 2
FCV 3
PT 3
TW 3
TT 3
FT 3A
FT 3B
FE 3
MM 3/1
PDI 3/1
XV 3
4″
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FLOW
FLOW
CHANGE
ISS
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APPROVED
CON-TECH a.s
DRAWING BY
PAL K. JACHØ
TYPICAL ARRANGEMENT
P & I DIAGRAM
DRAWING NUMBER
CTN 1292
1 OF 3
ISSUE
1
Flanse ref.
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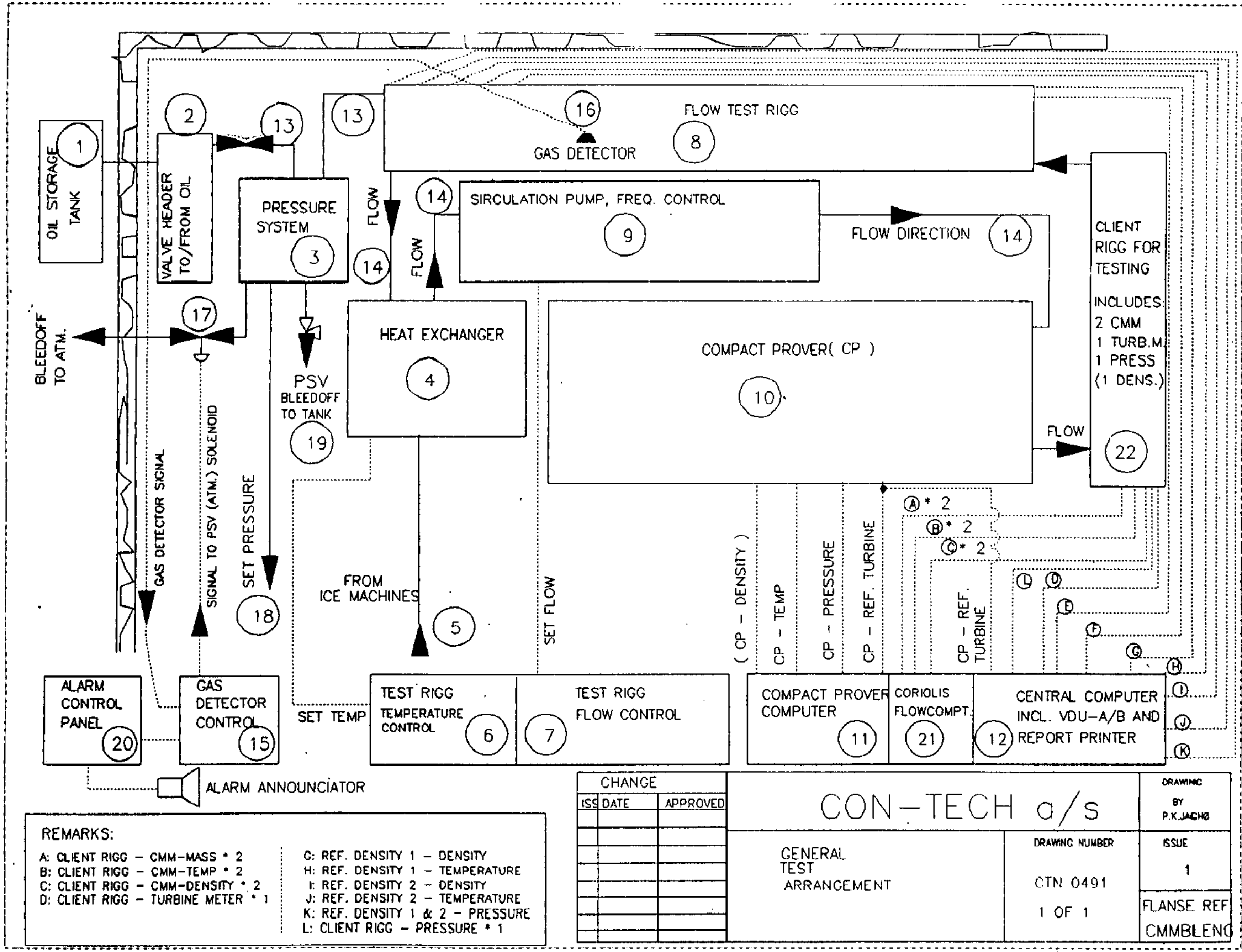
Fig. 1


OIL STORAGE TANK
VALVE HEADER TO/FROM OIL
PRESSURE SYSTEM
FLOW TEST RIGG
GAS DETECTOR
SIRCULATION PUMP, FREQ. CONTROL
FLOW DIRECTION
FLOW
HEAT EXCHANGER
COMPACT PROVER(CP)
CLIENT RIGG FOR TESTING
INCLUDES:
2 CMM
1 TURB.M.
1 PRESS
(1 DENS.)
BLEEDOFF TO ATM.
PSV
BLEEDOFF TO TANK
GAS DETECTOR SIGNAL
SIGNAL TO PSV (ATM.) SOLENOID
SET PRESSURE
FROM ICE MACHINES
SET FLOW
(CP – DENSITY)
CP – TEMP
CP – PRESSURE
CP – REF. TURBINE
CP – REF. TURBINE
A * 2
B * 2
C * 2
ALARM CONTROL PANEL
GAS DETECTOR CONTROL
SET TEMP
TEST RIGG TEMPERATURE CONTROL
TEST RIGG FLOW CONTROL
COMPACT PROVER COMPUTER
CORIOLIS FLOWCOMPT.
CENTRAL COMPUTER INCL. VDU-A/B AND REPORT PRINTER
ALARM ANNUNCIATOR
REMARKS:
A: CLIENT RIGG – CMM-MASS * 2
B: CLIENT RIGG – CMM-TEMP * 2
C: CLIENT RIGG – CMM-DENSITY * 2
D: CLIENT RIGG – TURBINE METER * 1
G: REF. DENSITY 1 – DENSITY
H: REF. DENSITY 1 – TEMPERATURE
I: REF. DENSITY 2 – DENSITY
J: REF. DENSITY 2 – TEMPERATURE
K: REF. DENSITY 1 & 2 – PRESSURE
L: CLIENT RIGG – PRESSURE * 1
CHANGE
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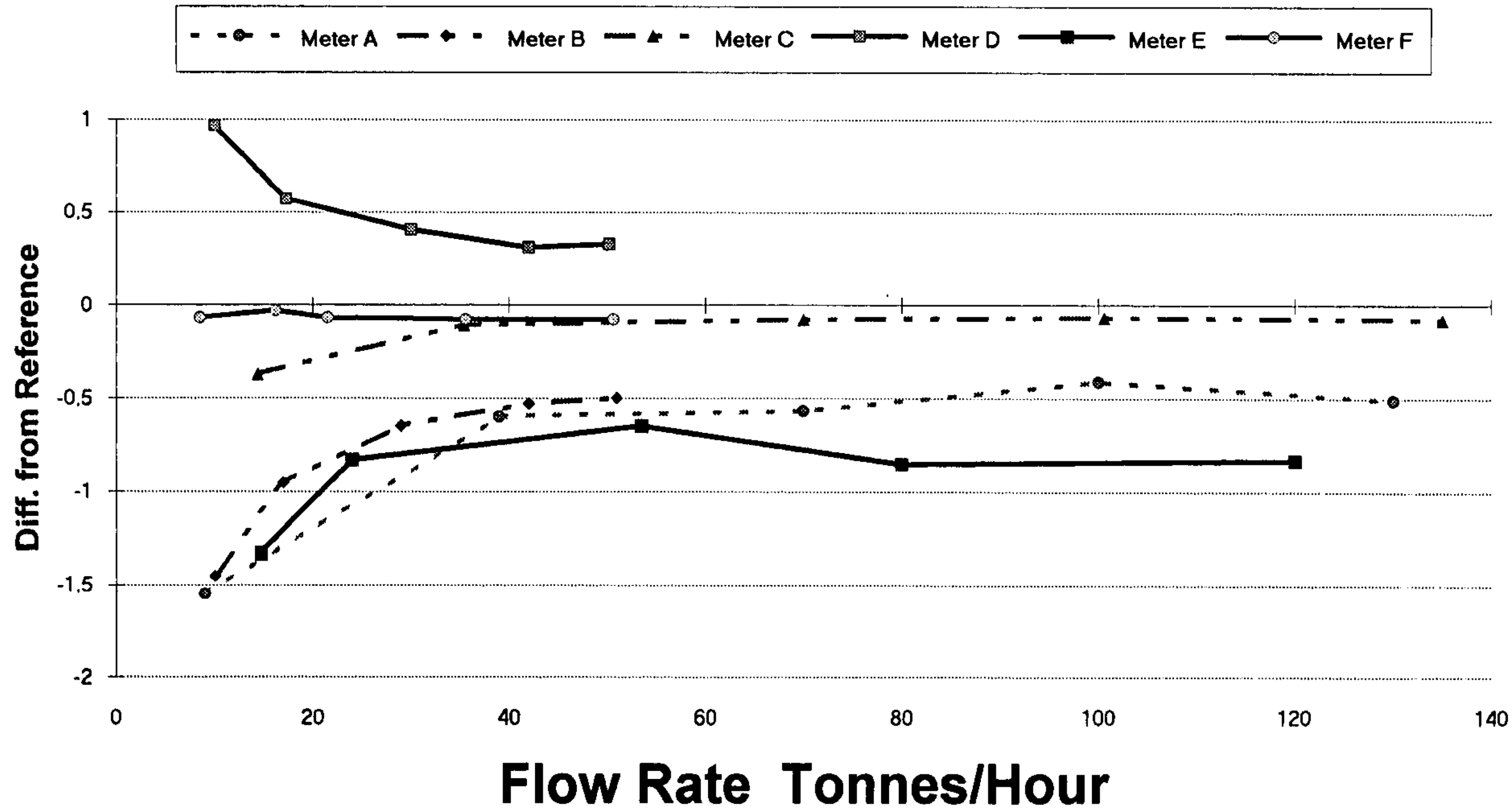
CON–TECH a/s
DRAWING BY P.K.JACHØ
GENERAL TEST ARRANGEMENT
DRAWING NUMBER
CTN 0491
1 OF 1
ISSUE
1
FLANSE REF
CMMBLENG

FIG.2

Initial Water Calibration



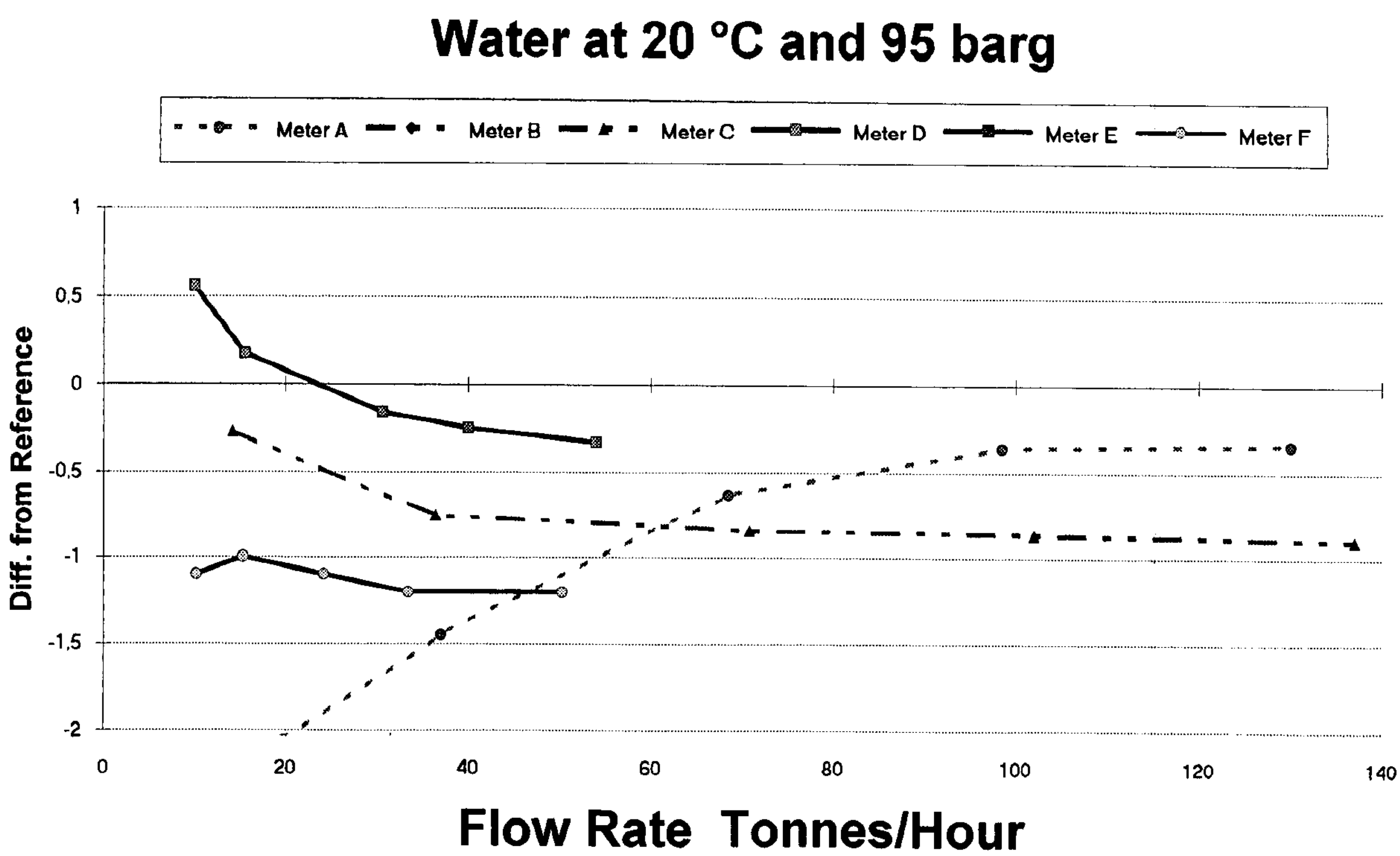
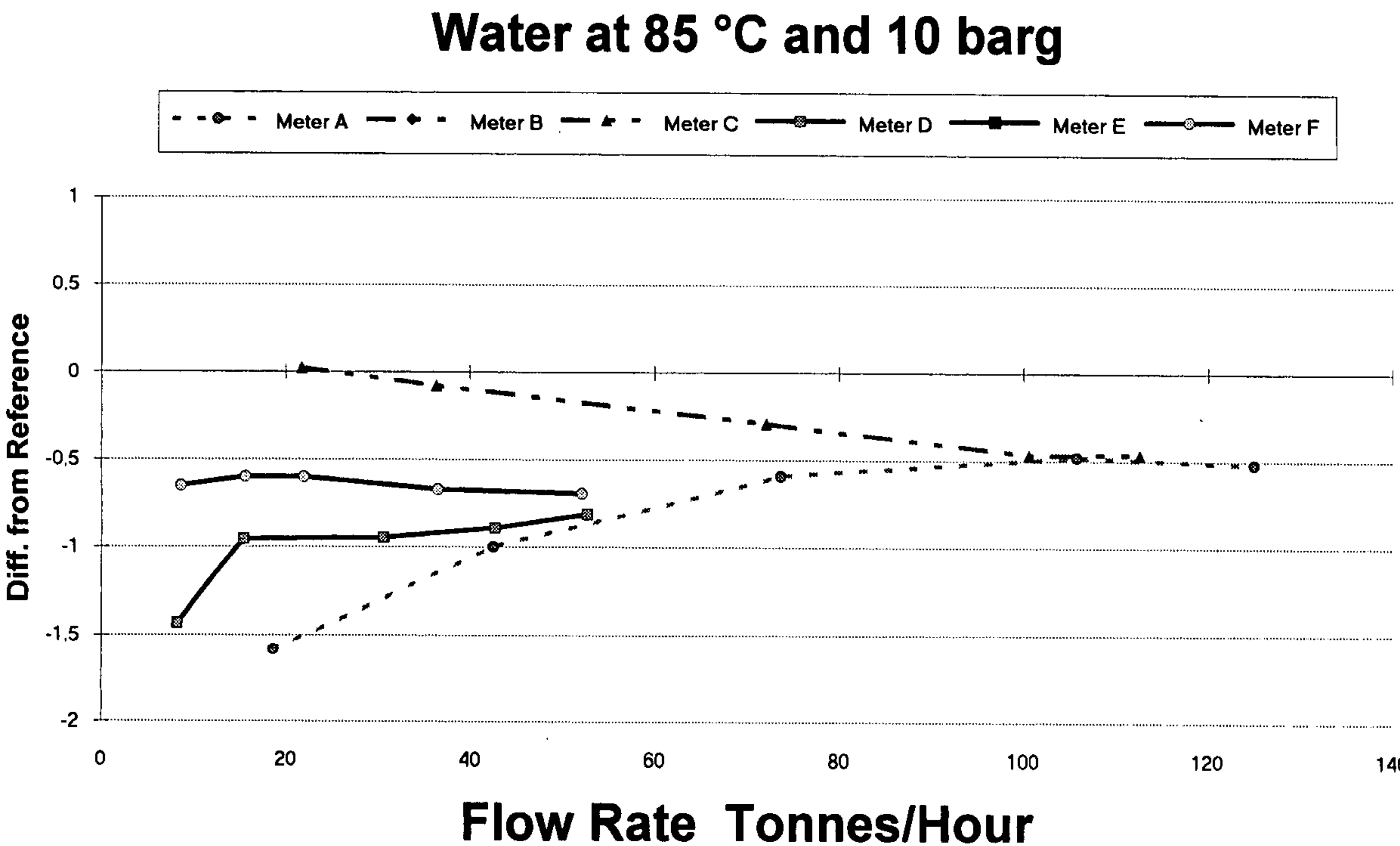

Water at 20 °C and 95 barg
Meter A
Meter B
Meter C
Meter D
Meter E
Meter F
1
0,5
0
-0,5
-1
-1,5
-2
Diff. from Reference
0
20
40
60
80
100
120
140
Flow Rate Tonnes/Hour

Fig. 4



Water at 85 °C and 10 barg
Meter A
Meter B
Meter C
Meter D
Meter E
Meter F
1
0,5
0
-0,5
-1
-1,5
-2
Diff. from Reference
0
20
40
60
80
100
120
140
Flow Rate Tonnes/Hour

Fig. 5

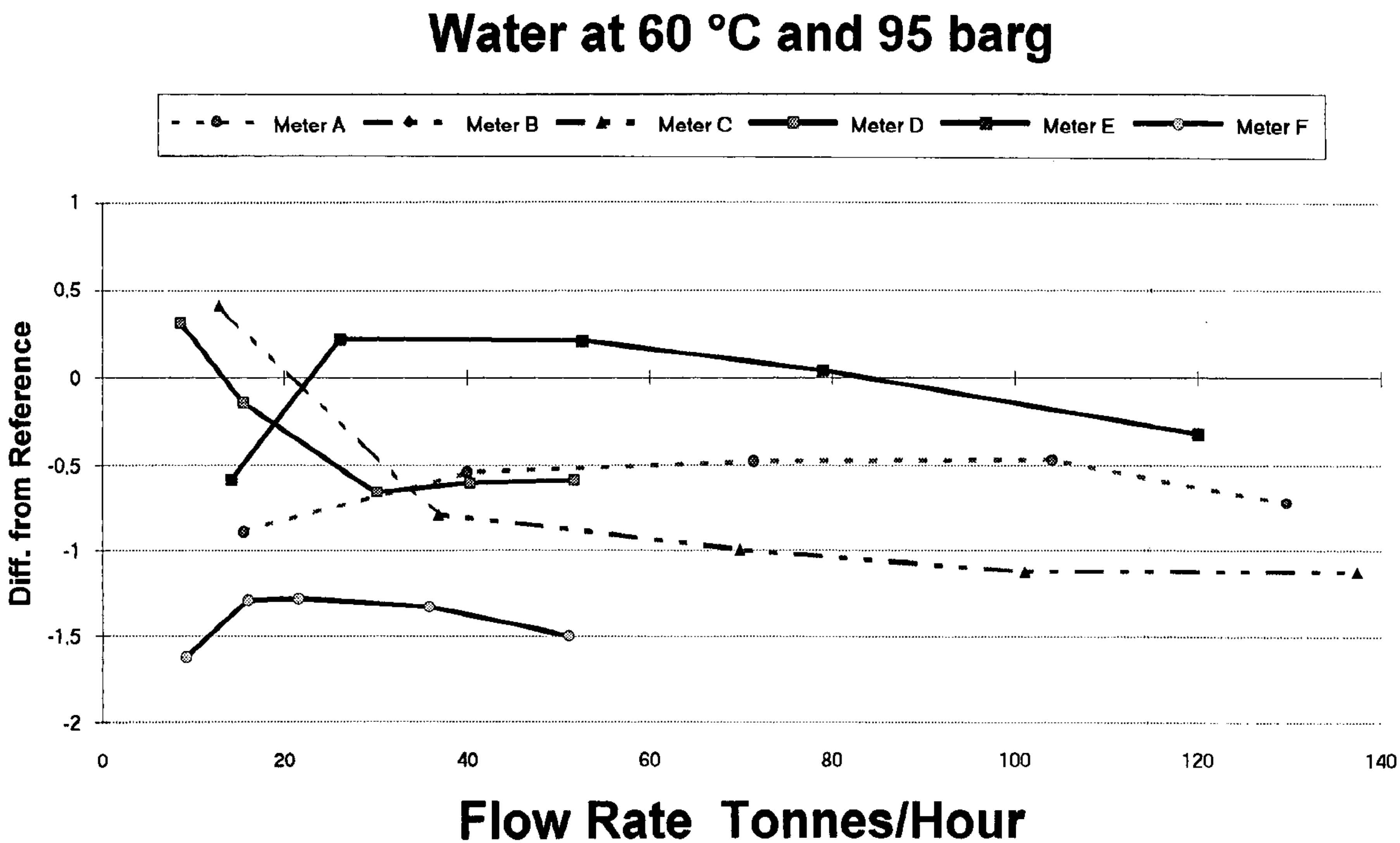
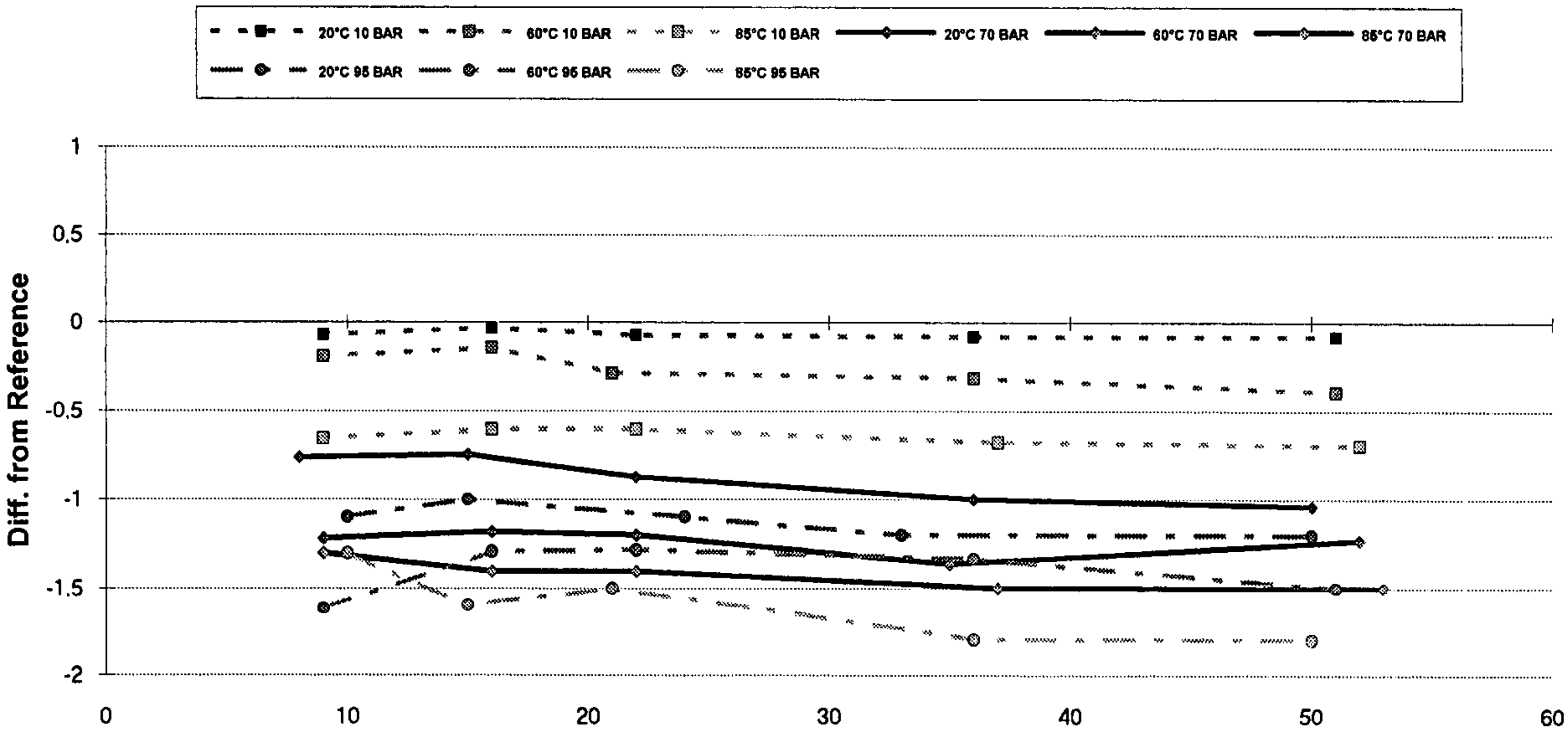

Water at 60 °C and 95 barg
Meter A
Meter B
Meter C
Meter D
Meter E
Meter F
Diff. from Reference
1
0,5
0
-0,5
-1
-1,5
-2
0
20
40
60
80
100
120
140
Flow Rate Tonnes/Hour

Fig. 6

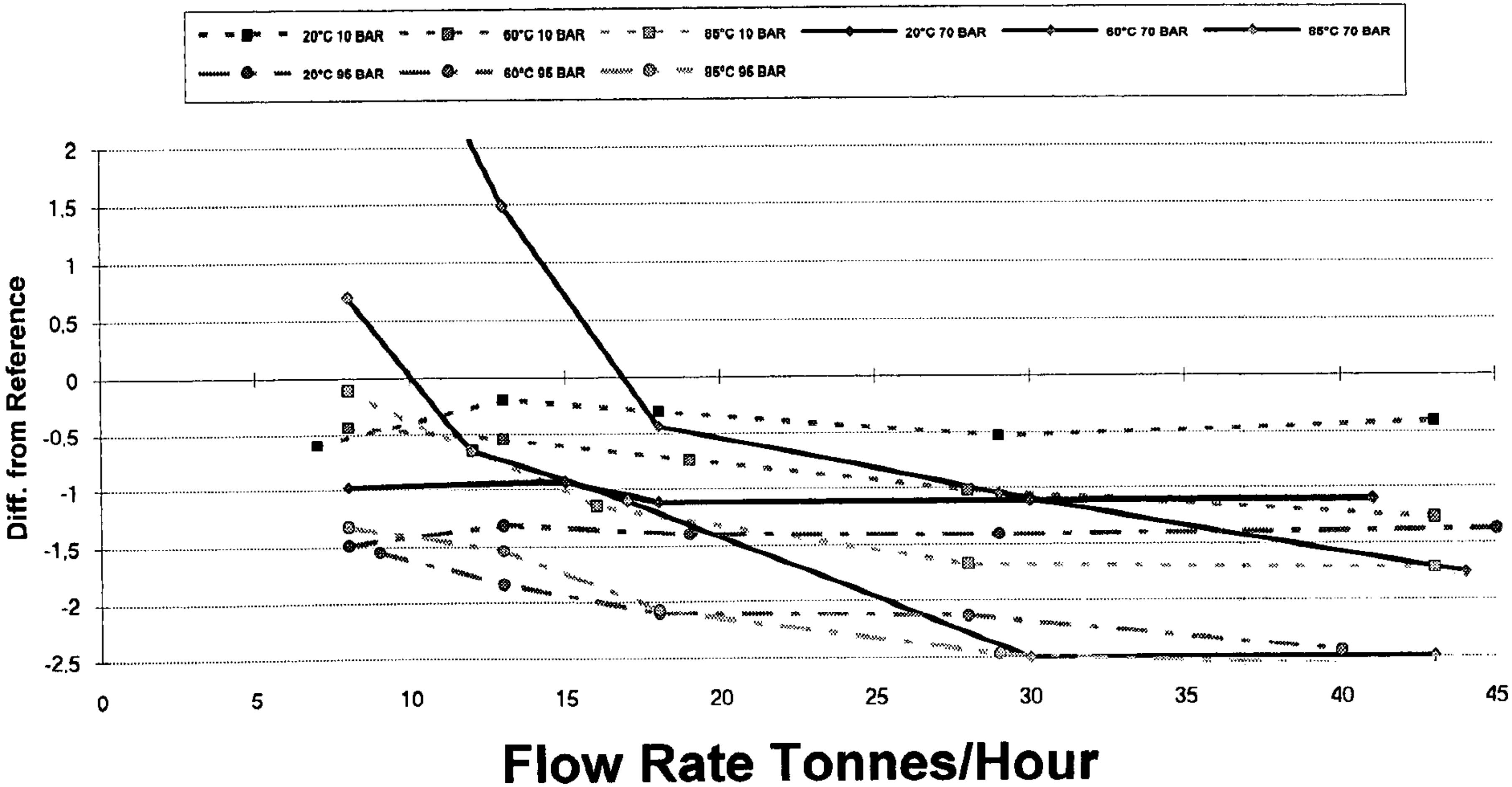
Meter F at all Water Points



Flow Rate Tonnes/Hour

Fig. 7

Meter F Crude Oil 0,89 kg/l and 19 cSt 20°C



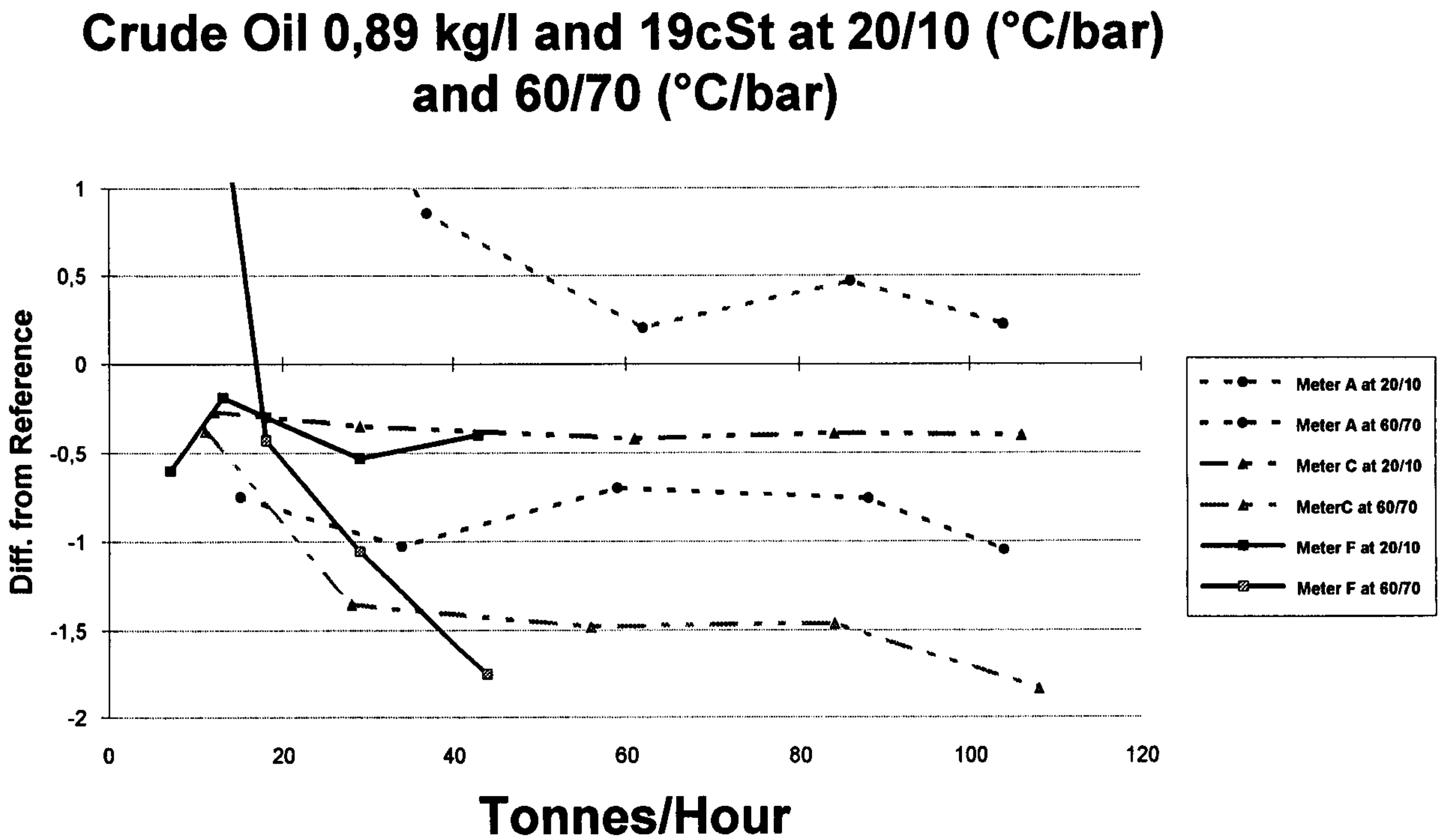

Crude Oil 0,89 kg/l and 19cSt at 20/10 (°C/bar) and 60/70 (°C/bar)
Diff. from Reference
1
0,5
0
-0,5
-1
-1,5
-2
0
20
40
60
80
100
120
Tonnes/Hour
Meter A at 20/10
Meter A at 60/70
Meter C at 20/10
MeterC at 60/70
Meter F at 20/10
Meter F at 60/70

Fig. 9

Naphtha 0,65 kg/l and 0,6cSt at 20/10 (°C/bar) and 60/70 (°C/bar)

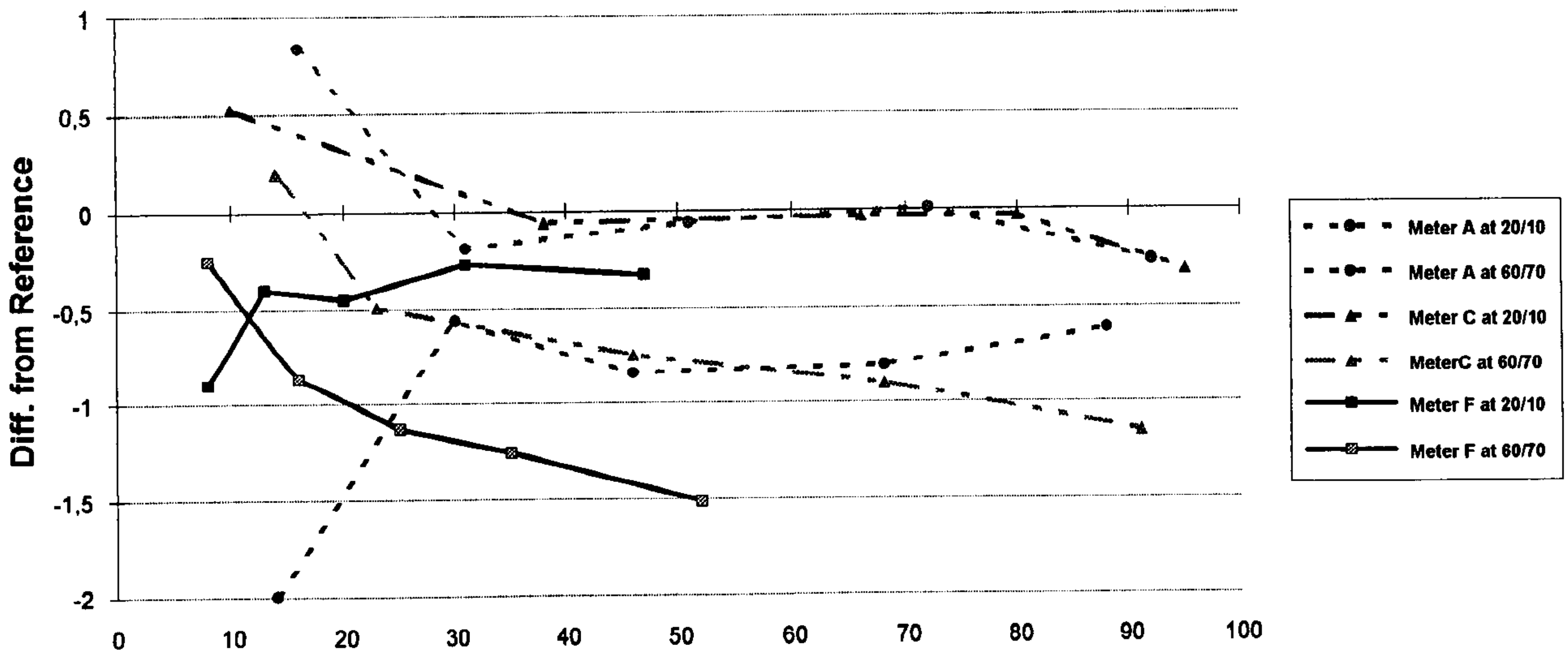
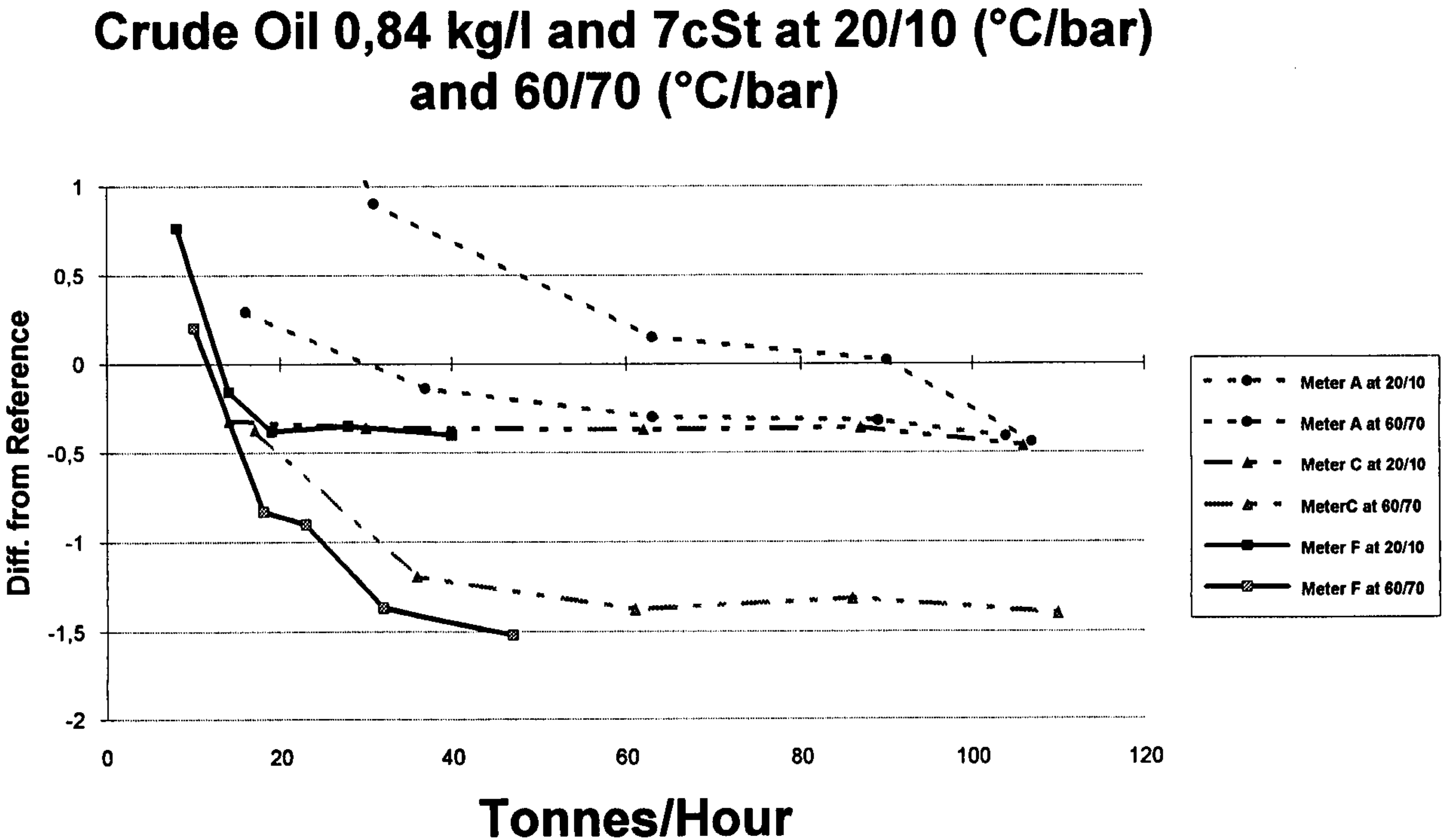


Fig. 10



Crude Oil 0,84 kg/l and 7cSt at 20/10 (°C/bar) and 60/70 (°C/bar)
1
0,5
0
-0,5
-1
-1,5
-2
Diff. from Reference
0
20
40
60
80
100
120
Tonnes/Hour
Meter A at 20/10
Meter A at 60/70
Meter C at 20/10
MeterC at 60/70
Meter F at 20/10
Meter F at 60/70

Fig. 11

Meter A at all Points Naptha

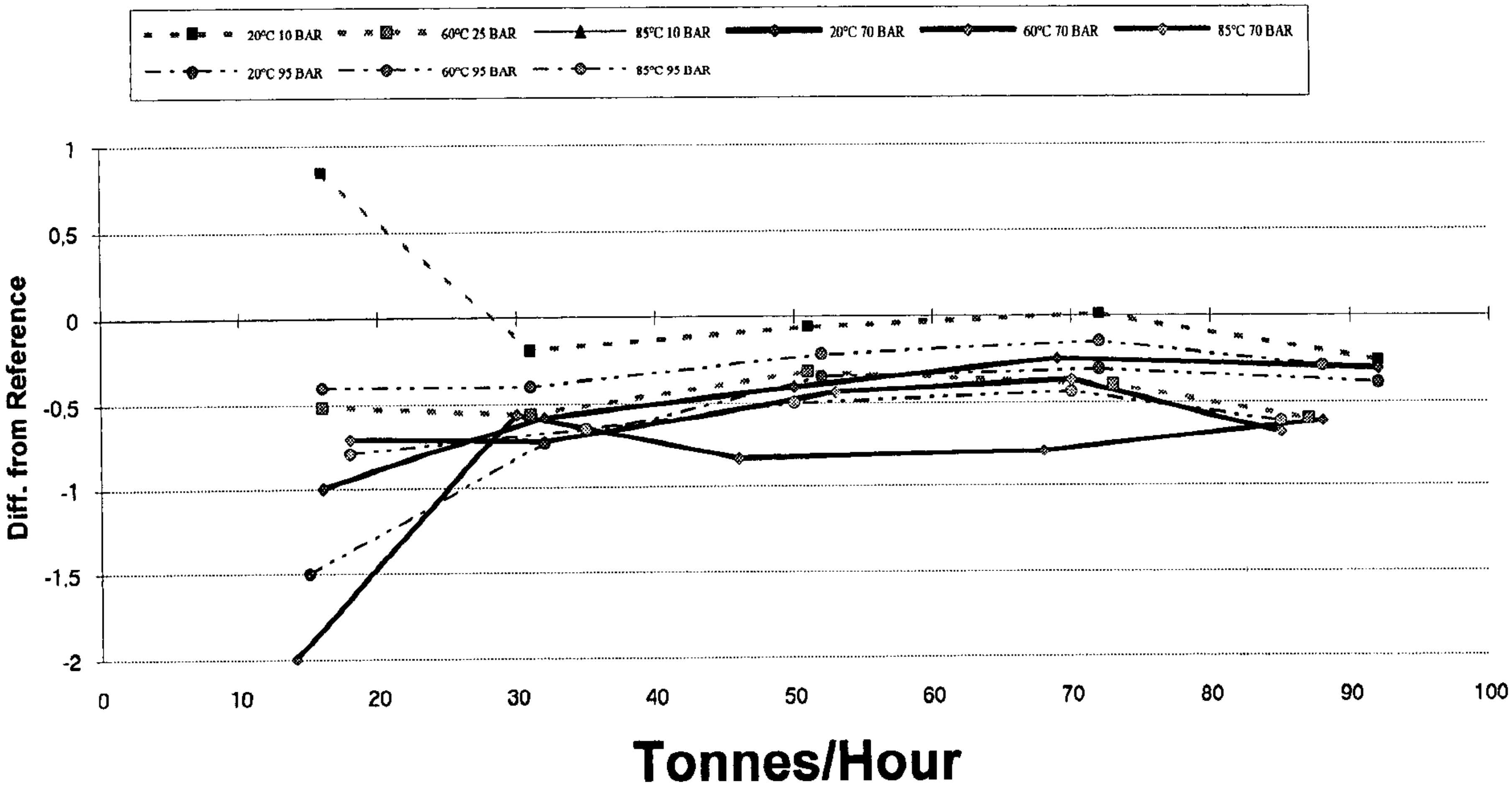


Fig. 12

Meter A at all Points Crude Oil (0,89/19)

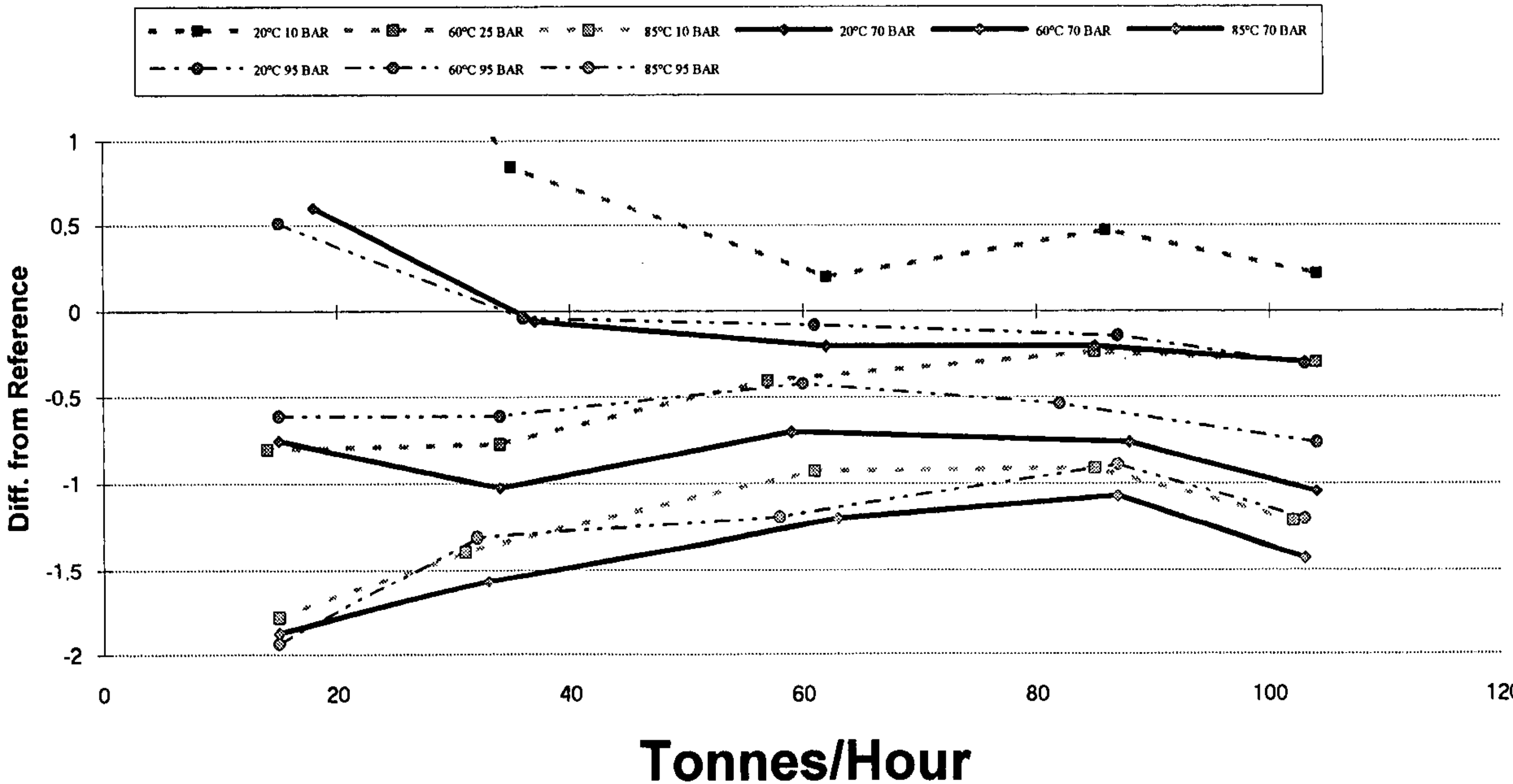


Fig. 13

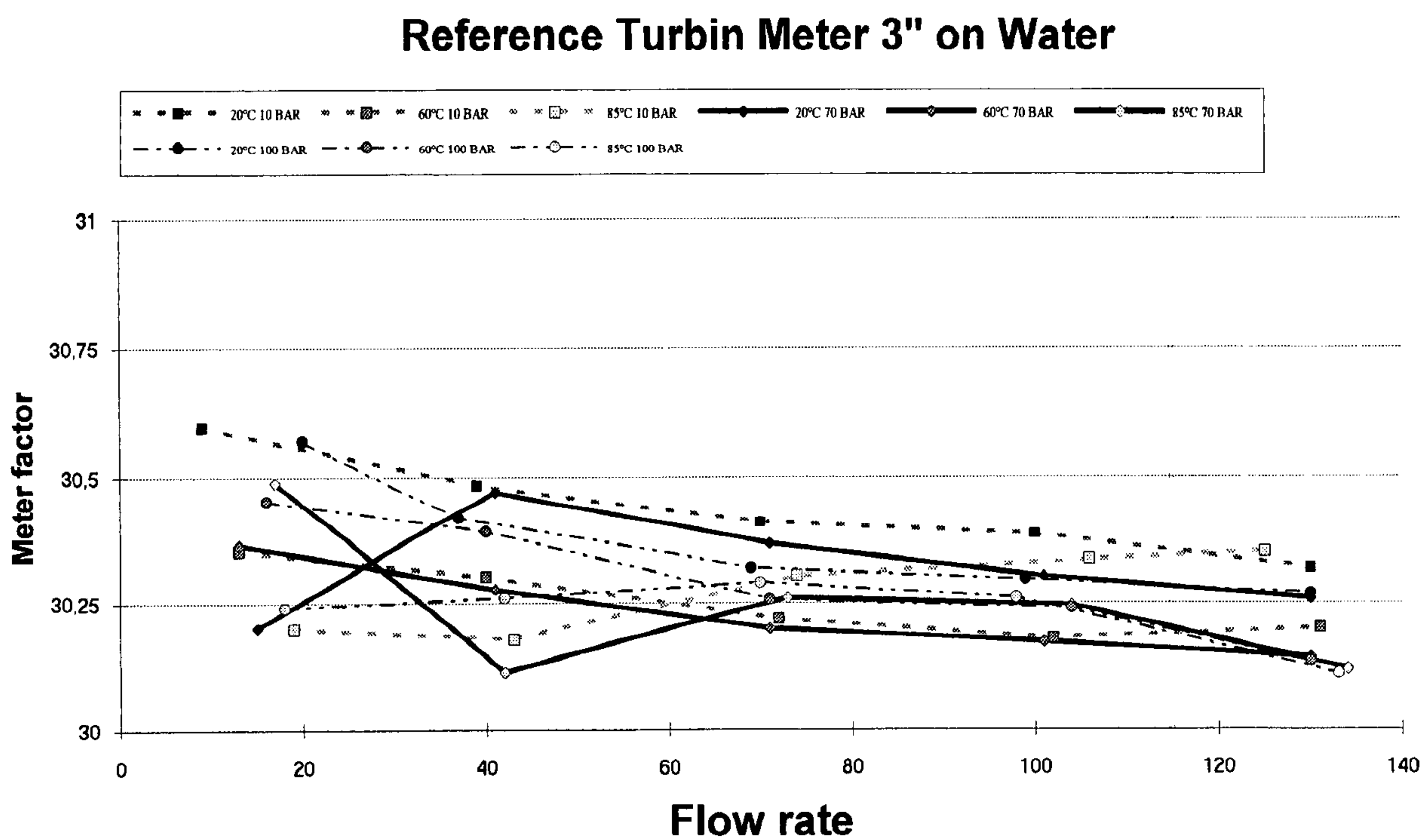

Reference Turbin Meter 3" on Water
20°C 10 BAR
60°C 10 BAR
85°C 10 BAR
20°C 70 BAR
60°C 70 BAR
85°C 70 BAR
20°C 100 BAR
60°C 100 BAR
85°C 100 BAR
31
30,75
30,5
30,25
30
Meter factor
0
20
40
60
80
100
120
140
Flow rate

Fig. 14

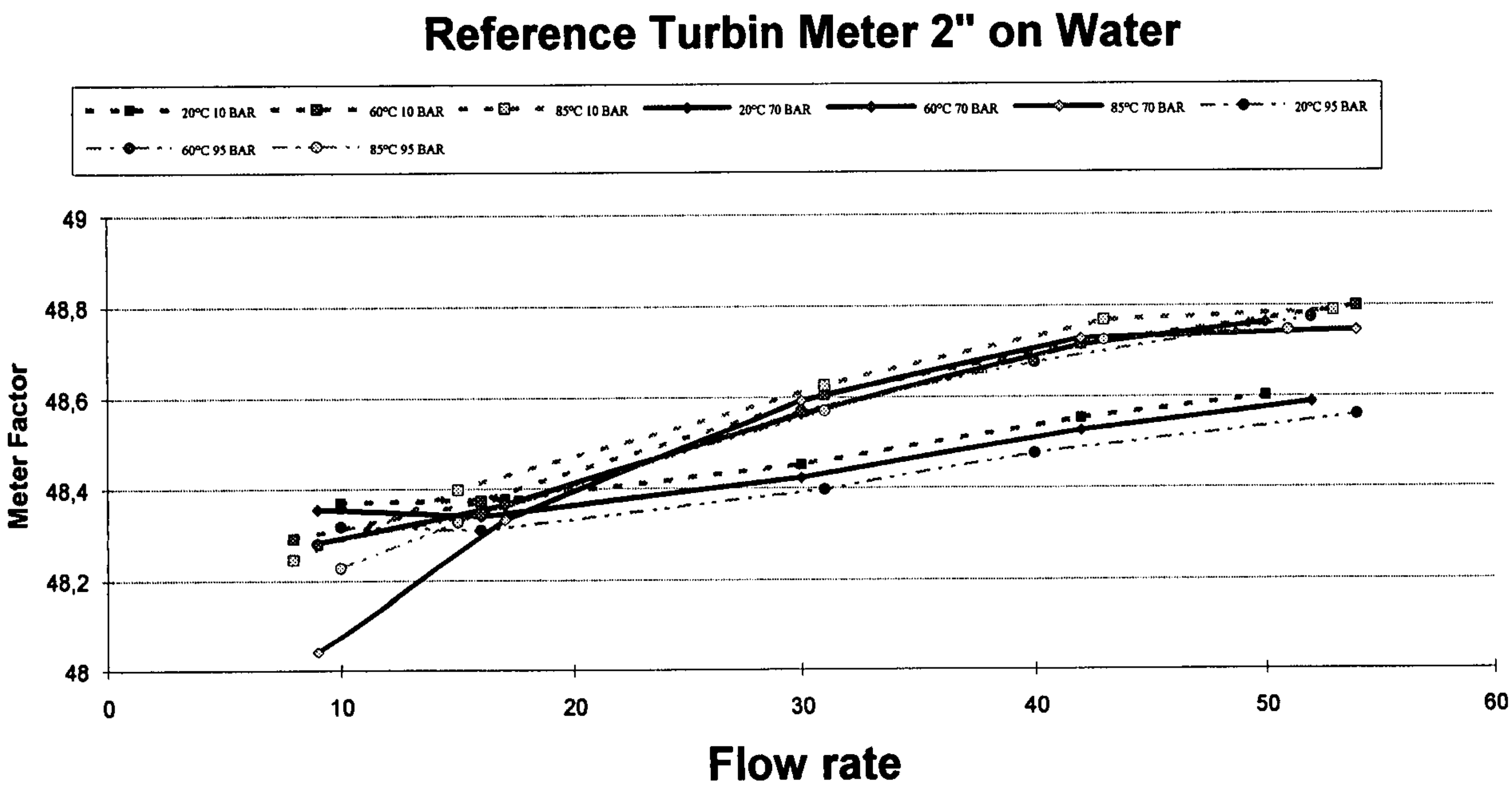

Reference Turbin Meter 2" on Water
20°C 10 BAR
60°C 10 BAR
85°C 10 BAR
20°C 70 BAR
60°C 70 BAR
85°C 70 BAR
20°C 95 BAR
60°C 95 BAR
85°C 95 BAR
Meter Factor
49
48,8
48,6
48,4
48,2
48
0
10
20
30
40
50
60
Flow rate

Fig. 15

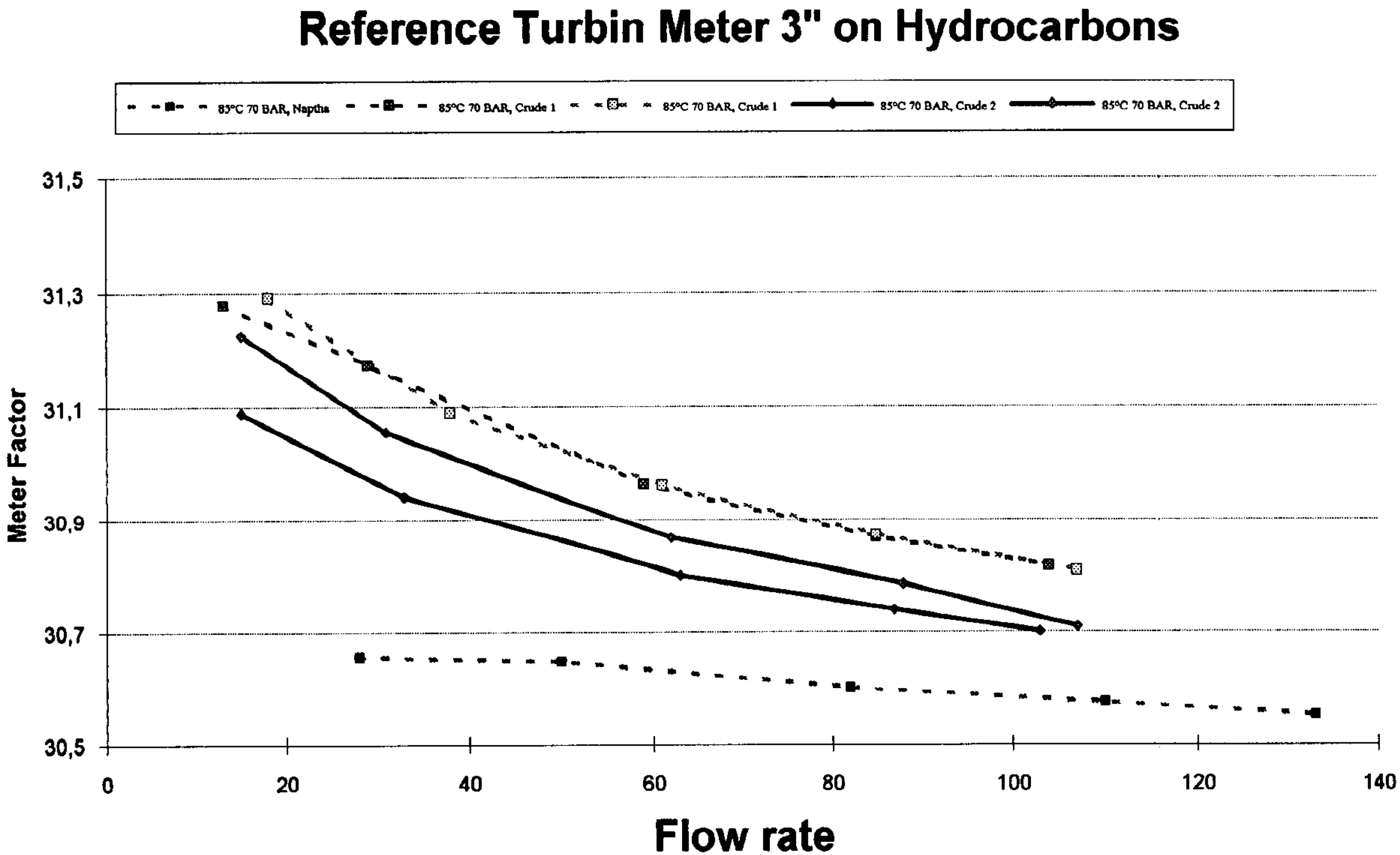

Reference Turbin Meter 3" on Hydrocarbons
85°C 70 BAR, Naptha
85°C 70 BAR, Crude 1
85°C 70 BAR, Crude 1
85°C 70 BAR, Crude 2
85°C 70 BAR, Crude 2
Meter Factor
31,5
31,3
31,1
30,9
30,7
30,5
0
20
40
60
80
100
120
140
Flow rate

Fig. 16

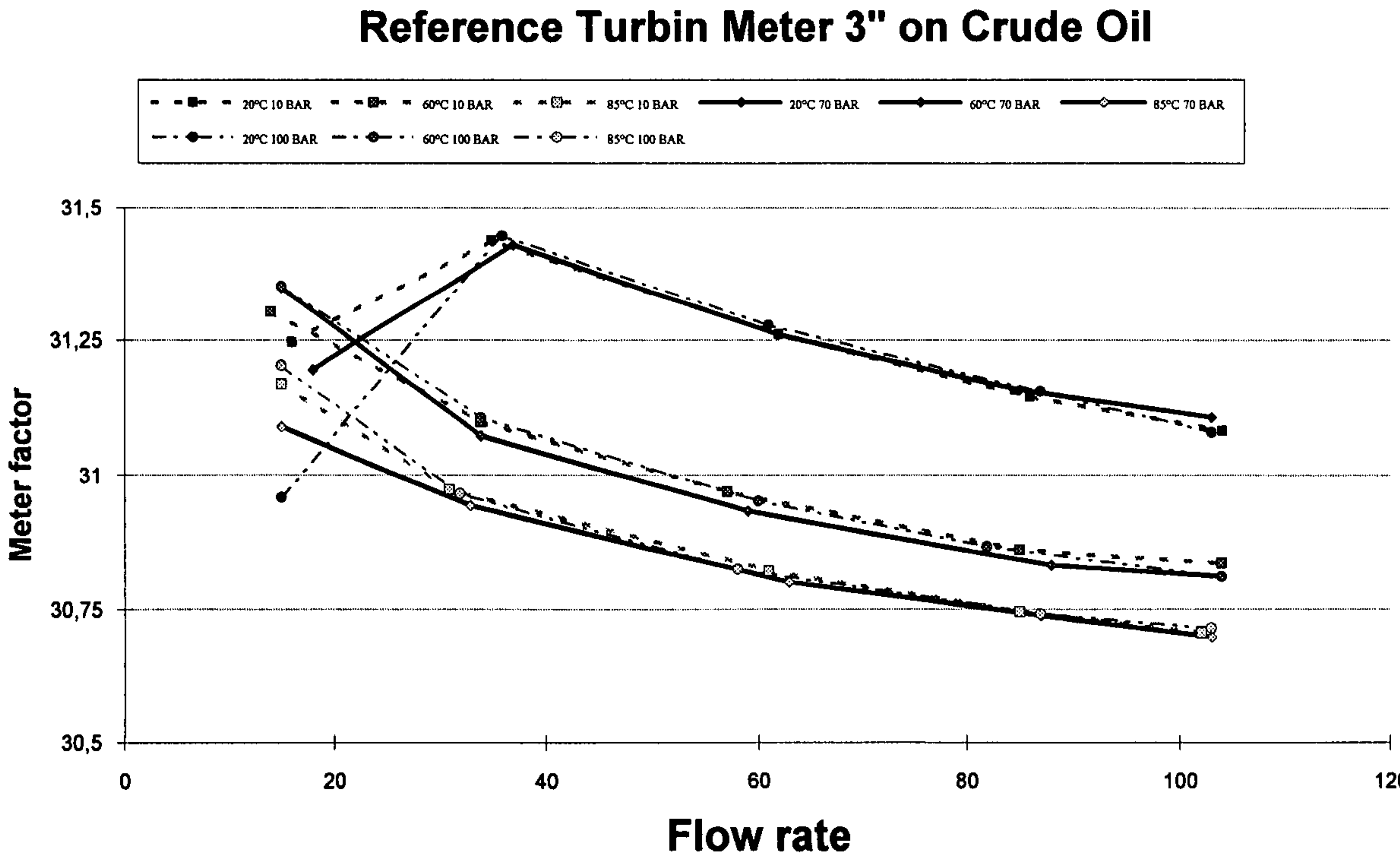

Reference Turbin Meter 3" on Crude Oil
20°C 10 BAR
60°C 10 BAR
85°C 10 BAR
20°C 70 BAR
60°C 70 BAR
85°C 70 BAR
20°C 100 BAR
60°C 100 BAR
85°C 100 BAR
Meter factor
31,5
31,25
31
30,75
30,5
0
20
40
60
80
100
120
Flow rate

Fig. 17

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.