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Understanding the unusual spinner response of small diameter continuous flowmeter in two-phase flow for reservoir management in inclined wells - a case study from Mehsana oil fields.

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Summary

Small diameter (1.69 inch) Continuous Spinner Flowmeter Tool (CFJ) is commonly deployed by Logging Services of ONGC in on-shore fields during Production Logging (PL) operation to measure flow rate of fluid in producing/injection wells. It is observed from field experience that spinner responses of such tool are sometimes unusual and at times bizarre in a deviated producer well, flowing with two-phase at low flow rate. Flow meter logs indicate an apparent negative flow (flow reversal) against the producing zone though the production is confirmed from Temperature log and surface data. True volumetric estimation of producing fluids under such circumstances is affected by non-representative flow meter data and often the log interpretation is subjective.

An attempt has been made in this study to understand the anomalous behaviour of spinner responses in inclined well of two phase fluid and suggest remedial measures to calculate the realistic fluid velocity. Two field examples of anomalous flow responses (oil-gas and oil-water) are illustrated in this paper from oil fields of Mehsana Asset (ONGC, India).The study provides information to the PL interpreter to resolve anomalous spinner responses and suggests ways to select the proper spinner Tool for Production Logging in two phase flow regime specially in inclined wells.

Introduction

In the oil fields of Mehsana, India slim Continuous Jeweled Spinner Flowmeter (CFJ) is normally used for flow measurement to find out layer wise contribution or to detect the source of production. Our experience with this tool is as follows:

i) In vertical producer wells either having a single or multiphase flow of rates 5m^3/d or more, this tool gives a fairly consistent and realistic measurement.

ii) In water injection or effluent disposal wells no ambiguities in interpretation has been observed in both vertical and inclined wells.

iii) However, in deviated wells (>10°) with other than single phase flow, an unusual response which is not consistent with Temperature, Fluid-density and Water-hold up logs were observed. The flow meter response was also not matching with surface flow rates.

It was noticed that even against producing zones, the spinner response is negative relatively in two- phase regime. In order to ascertain the findings based on the unusual response, first the quality of the recorded data was ensured by making extra up and down passes and then the analysis of data was attempted.

This paper highlights the identification of the unusual response of the slim Continuous Flowmeter and suggests ways to recognize the same and to avoid making ambiguous interpretation based on such data. It also proposes alternate methods to estimate realistic volumetric flowrate under such condition other than spinner data. Two field examples of anomalous spinner response from oil fields of Mehsana have been illustrated and discussed as case study in this paper.

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Continuous Jeweled Spinner Flowmeter

Continuous Jeweled Spinner Flow meter (CFJ) uses an impeller to measure flow velocity. The impellers are mounted on low friction jeweled bearings to reduce the mechanical threshold of the spinner and improve sensitivity to fluid flow. Rotation of the spinners is sensed by zero drag Hall Effect sensors, allowing the measurement of flow rate. Tool output is revolution per second (rps) which is related to the flow velocity in the pipe. Normal output is 10 pulses per revolution with directional indication and generally two roller centralizers are used to centralize the tool.

Anomalous Response

The theoretical continuous spinner response in a producing vertical well, with single phase or multiphase flow, is shown in Fig-1. Step wise increase in spinner revolution against zone "A" and "B" represents the production contribution from different zones. However, Continuous spinner logs may respond as shown in Fig-2 in the interval just against the perforation "A" if the section of the borehole is deviated and the zone is producing two or more phases of differing densities. In such a condition it shows an apparent down flow even though there may be a net up flow in the well. The effect is seen when there is two-phase flow (water-oil or oil-gas) at low flow rate and is pronounced if one phase is gas, in a deviated well bore.

There are two factors behind such anomalous behavior, one is Flow regime and another is Tool centralization.

i) Flow Regime

Wells often produce flow consisting of two or three phases at a time. Due to different fluid properties between phases, more than one flow regime might be encountered in the interested interval. Flow regimes are of two types, one is gas-liquid and the other is liquid-liquid. Parameters which influence the flow regime are i) Total flow rate, ii) Pipe diameter, iii) Physical properties of each phase and iv) Pipe roughness. In vertical well, an even distribution of the phases across the pipe produce a positive flowmeter response. When the well is inclined, the flow pattern is modified. Different phases of fluid are stratified against the inclined section and an area of transition exists between the flow pattern regions. With increasing deviation angle, the lighter phase (oil or gas) flows to the higher side of the pipe and occupy there. Some heavier fluid is lifted by the lighter phase bubbles but continually falls out and traveling back down on the low side of the pipe. This causes a circulation of heavier fluid while moving up. The spinner records this anomalous down hole flow which offsets the true fluid velocity and in low fluid velocity wells may even show negative flow. This phenomenon is more pronounced in 2 phase flow with low velocity than in 3 phase flow which tends to be more turbulent or having better mixing. However, this effect can be severe even for down hole flowrate as high as 150 m^3/d and higher and if one of the phases is gas. The effect of flow regime in inclined well on spinner response is illustrated in the Fig-3. Slim Continuous Flowmeter reports incorrect apparent downward fluid flow under the circumstances though there is net flow of fluid up the pipe.

ii) Tool Centralization

Spinner response of CFJ tool is affected by multiphase fluid flow in inclined well even when the tool is centralized. If it is not centralized the effect is more pronounced even in slight deviation. In deviated interval the tool centralizers may rest on the lower side of the pipe due to tool gravity making the tool decentralized. Fig-4 shows the effect of well bore deviation on a slim continuous spinner held stationary at various angles of inclination. The response of the centralized tool holds up well up to about 10 - 15° inclination. However, if the tool is not centralized, the response indicates a down flow, even at only 2° angle of well bore. This indicates that tool centralization could be more critical.

In summary we may conclude that the causes of anomalous behaviour of slim Continuous Flowmeter are i) Inherent nature of two-phase flow regime which results in circulation of heavier fluids, ii) Deviation of the well and iii) Decentralization of the tool.

Laboratory Tests

Production logging tools from three service companies were tested in multi phase flow in an inclined flow test facility at Marathon Oil Co.'s Denver research Centre.[1] Liquid flow rates ranging from 11 to 540 m^3/d and gas rates from 0 to 210 m^3/d were chosen to simulate down hole condition during the tests. To simulate the wide range of well deviations, the pipe angle also varied from zero to 60° from vertical. Production logging tool responses were measured over this range of conditions to understand tool behaviour and to try to correlate measurements with actual flow rates.

A similar experiment was conducted by Atlas Wireline Services in a Flow Loop at Houston, Texas. The Flow Loop is a multiphase flow simulation system capable of delivering simultaneous and independent flow rates of oil, water and gas into the manifold at the bottom of a 30ft long transparent test section (inclinable) which contains the logging instruments. The testing was carried out in three categories i) by holding total flow at a fixed rate and varying the ratio of the constituent fluids with respect to one another, ii) by maintaining constant ratio between constituent fluid flow rates and varying the total rate and iii) varying the flowing parameters in a randomly.

In both experiments it was observed that production logging tool responses were adversely affected by flow pattern in multiphase flow in inclined well. In gas-liquid flow in a slanted pipe, slug flow was the prominent flow regime, whereas in oil-water two-phase flow, a stratified flow was common.

Production logging tools that measure localized quantities do not represent volumetric flow rates, average fluid density or holdups. Flowmeter spinner response indicates unusual reverse flow due to establishment of non uniform flow profile. Density and capacitance tools read the phase from low side of inclined pipe and make their responses suspect.

Identification Of Anomalous Response

A quick analysis of Temperature, Fluid-density and Water-holdup log response is to be made and compared with the Flowmeter responses. If the Flowmeter response is not consonance or rather it is in reverse direction (negative compared to sump response) then it should be examined whether there is a) Two-phase flow b) Deviated well c) Ecentered spinner tool. This may explain the flowmeter response.

The negative response of the spinner is the effect of the heavy phase (water) falling back in a localized interval. It is only part of the fluid movement which had gone up plus an additional quantity (a correction factor) which could not be accounted due to its lighter density (and thus having lesser impact on the spinner). Spinner covering only the lower side of the casing due to ecentralisation and deviation of the well.

Case Study-1

Production logging was carried out in Well # X of Nandasan field to ascertain layer wise production from two layers "A" (1330-1332m) and "B" (1316-1320m).Well was producing liquid @16 m3/d with 2% water cut through 5mm bean (FTH 12ksc) for a period of 551 days. It is a "L" profile well with angle 19° against the zones as shown in Table-1.Temperature, Gamma ray, CCL, Pressure, Flowmeter, Fluid density and Water-holdup logs were recorded in the well. Smaller diameter CFJ tool was used for flowmeter logging. A merged down passes log is exhibited in Fig-5. Significant change in temperature gradient against the zone "A" and a slight change against zone "B" shows that top 1m of bottom zone is main producer of liquid and top zone is contributing a little amount. This result is corroborated with the change of fluid density level against the bottom zone. Water hold up and density log indicate the production of either water or emulsion. But, flowmeter logs recorded at three different speeds show negative spinner response against the main producing zone "A". The logs show an apparent down flow into the zone though the actual flow is up in the well bore which is also confirmed from the surface data.

This unusual flowmeter response is attributed to two phase (oil-water) fluid flow at 16m3/d in a deviated interval (19°). Such response in interval "B" is subdued due to lesser contribution.

Case Study-2

Production logging with log suites Temperature, Pressure, Gamma ray, CCL, Flowmeter, Density and Water-holdup were carried out in Well # Y to ascertain the layer wise contribution and source of water production from layers "A"(1199-1201.5m), "B"(1191-1194.5m) and "C"(1185-1187m). Well # Y is a "S" profile well and zones are lying in inclined section of maximum angle 24.75°. The well was flowing with oil (5 m3/d), water (7.5 m3/d) and gas (580 m3/d) through 5mm bin. Production logs of the well are presented in Fig-6**.** Slope change in Temperature log and abrupt shift in Water-holdup log indicate that bottom zone "A" is producing emulsion and top zone "C" is the main producer of hydrocarbon (oil-gas). As water cut is within 40%, Water-holdup log is very sensitive to fluid phase change. Density tool is responding to heavier fluid and is less sensitive. Flowmeter log against bottom zone "A" is indicating apparent negative flow whereas against top zone the response is normal. It may be due to higher flowrate which is seen from flowing temperature response.

The unusual spinner response in this case is due to two phase (oil-water) flow in deviated (24.75°) pipe along with the effect of tool decentralization.

Computation Of Bulk Flowrate

Volumetric flow rate (Q) is computed by using $\mathbf{Q=1.40xCxVaxd^2}$ where C=velocity correction factor (0.83), Va = apparent flow velocity measured by spinner, d=internal diameter of casing. This technique was applied for zone "A" in case study-1&2 but the results do not match with production data and appear to be doubtful.

A possible quantitative technique for flow rate measurement in such case is to use Temperature log which is unaffected by well deviation. The horizontal distance 'ΔT' between the geothermal profile and the asymptote of temperature line indicates the mass flowrate which can be expressed as

$$\Delta T = bM/G;$$

where b=coefficient depending on fluid and formation thermal conductivity. G=geothermal gradient, and M=mass flow rate. The limitation of this method is that the tubing and packer usually appear within a short distance above the perforation and such asymptote is not apparent.

Romero-Juarez adapted a method in his work for computation in the field by using the equation

$$Q = (T_{fz} - T_{Gz}) / [1.66 C_f \rho_f f(t) \text{ grad } T_{fz}]; \qquad \text{(a)}$$

where T_{fz} =hole fluid temperature at any given depth z, T_{Gz}=corresponding geothermal temperature, grad T_{fz}=slope of the temperature curve at depth z, C_f =specific heat of wellbore fluid, ρ_f=fluid density and f(t) is a function which accounts for time variation of heats transfer to the Earth given by equation

$$f(t) = -\ln [r_{ce}/2\sqrt{kt}] - 0.290 \qquad \text{(b)}$$

where r_{ce}= outer radius of casing, k= thermal diffusivity of formation and t=total time of production

In this method the entire exponential segment of temperature log is considered irrespective of its asymptotic position. The well should flow for at least one hundred days in order to get accurate value of f(t) and a base temperature log is required before production starts to know geothermal temperature.

The above method is applied in case study-1 to compute volumetric flowrate of Well # X as it is producing two-phase fluid from a single zone. Curved segment of temperature log above producing zone "A" is used for mass flowrate estimation as shown in Fig-7. From log at 1325m depth it is found that T_{fz} = 166.1°F, T_{Gz}=152.9°F and grad T_{fz}=0.0122 °F/ft. With production time (t) = 551 days, a thermal diffusivity k = 0.96 sq ft/day, and an external casing radius r_{ce}=0.229ft (5 ½-in,17 ppf), equation (b) is used to find f(t)=4.98. Assuming C_f=1 btu /lb-°F for simplicity and ρ_f=0.87 gm/cc from density log, volumetric flowrate in downhole condition is measured as Q= 150 BPD=24m^3/d or 20m^3/d at surface (using oil formation volume factor=1.2). When compared with surface production data (16m^3/d liquid) with 2% water cut, the result is little higher. This is possibly due to the following factors.

a) T_{Gz} value at 1325m is taken assuming local geothermal gradient 5.5°F/100m as there is no base temperature log available. b) Fluid density value used is affected by tool ecentralization in deviated section. c) Actual production time might be less as the well was frequently shut down during testing procedures. d) The effect of different fluids in the annulus, kinetic energy, friction and Joule-Thompson expansion were neglected in the model.

Thus, Q(actual) = Q(measured) x K; where "K" is a correction factor (0.8) which can be improved by taking care of above factors. The improved "K" can be used to estimate realistic volumetric flowrate from multiple layers of the same well or from different wells producing under same borehole conditions.

Spinner Tool Selection

From study it is found that CFJ tool is good for logging in vertical and high fluid velocity wells, such as gas wells as the impeller is more like a turbine. CFJ tool also behaves satisfactorily in water injection wells irrespective of well profile because of single phase flow. But, the tool response is affected by well deviation and centralization in low multiphase flow regime.

Theoretically, Diverter Flowmeter gives good results in deviated well because the device directs the flow into flow housing where it is measured by an impeller. Unfortunately, the device is not suitable for oil fields in Mehsana as the impeller may get jammed due to presence of heavy oil and wax in borehole which is a common problem.
Thus for Mehsana oil fields an option would be to run Fullbore Spinner Continuous Flowmeter for production logging in all type of wells. The tool spring open to the full bore position after emerging from the bottom of tubing and sample a large (50-75) % fraction of the borehole. The tool is less affected by decentralization and well deviation compared to slim spinner continuous flowmeter.

Conclusion

1) In low flow rate multiphase well, Slim Continuous Flowmeter tool may give ambiguous spinner response at times and flowrate determination from such flowmeter reading may not be realistic. A methodology needs to be developed to recognize unusual responses from flowmeter and apply correction to arrive at a reasonable estimate of flow rate.
2) Fullbore Continuous Flowmeter is the appropriate tool for PL job in deviated wells of Mehsana oil fields having low flowrate as well as heavy oil production and wax problem.
3) Temperature log can be used as alternate method to estimate volumetric flowrate if spinner response is spurious.
4) Flow regimes can be differentiated in a better way by using advanced PL tools, with multiple probes designed for inclined wells.

References

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5) James J. SMolen; "Cased Hole and Production Log Evaluation"
6) M.R.Curtis; E.J.Witterholt; "Use of the Temperature Log for Determining Flow Rates In Producing Wells" Paper SPE 4637, 48th Annual SPE meeting, 1973

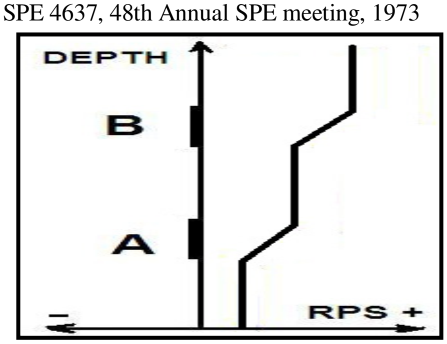

Fig-1: Normal spinner response in producing well

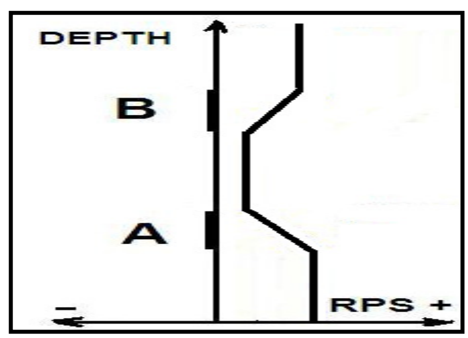

Fig-2: Anomalous spinner response against zone"A" in producing well

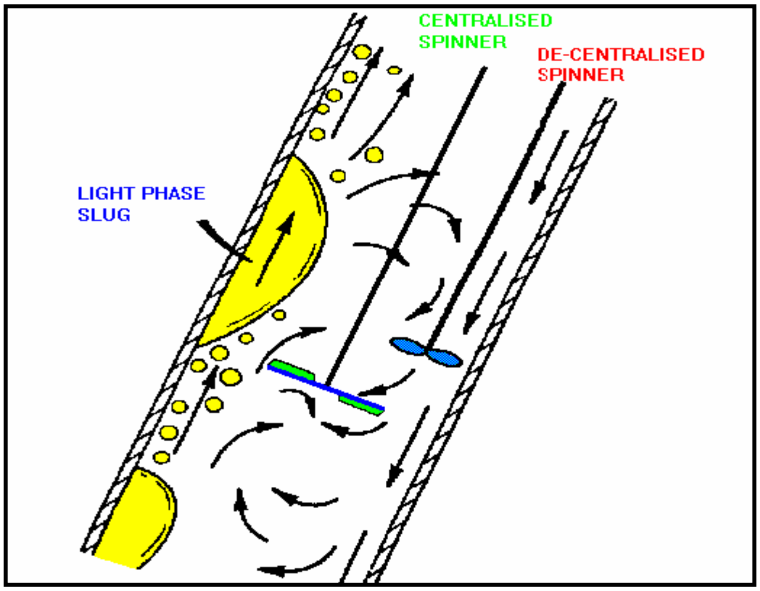

Fig-3: Illustration of anomalous response
(Courtesy Sondex PLT documents)

Well # X		Well # Y	
Depth(m)	Angle(deg)	Depth(m)	Angle(deg)
1005	21.5	1068	23.75
1024	21.25	1075	24
1043	21	1085	24
1062	20.75	1087	24
1081	20.5	1094	24.25
1100	20.5	1113	24.5
1119	20.5	1114	24.5
1138	20.25	1132	24.5
1157	20.25	1141	24.5
1176	20.25	1151	24.75
1195	20	1159	24.75
1214	20	1170	24.75
1233	20	1180	24.75
1252	19.75	1185	24.75
1271	19.5	1188	24.25
1290	19.5	1191	24.25
1309	19.25	1194.5	24.25
1328	19	1199	24.25
1347	19	1201.5	24.25
1366	18.75	1208	23.25

Table-1: Well deviation data

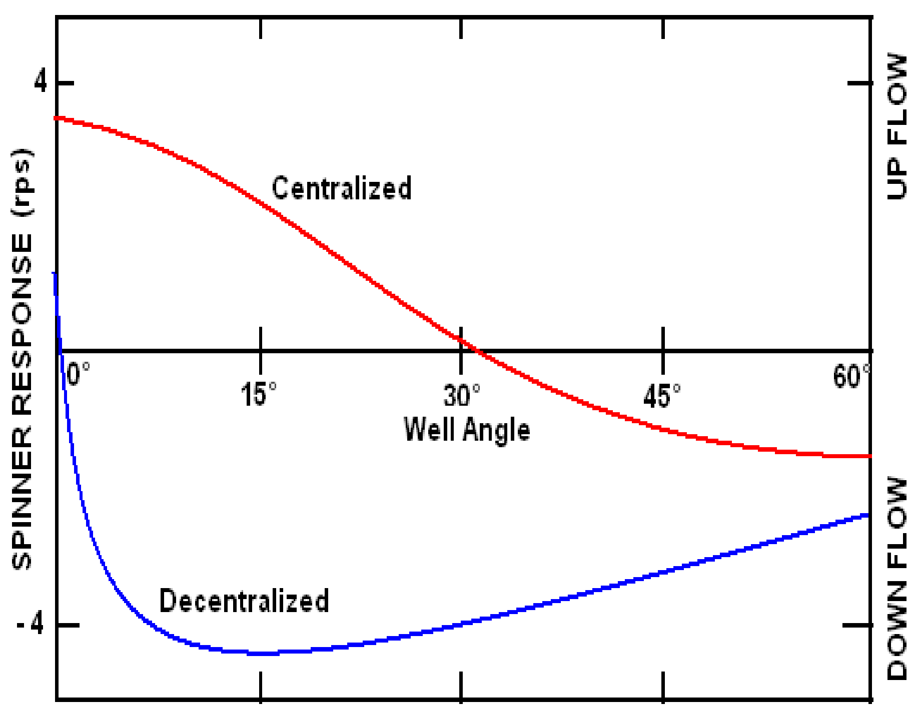

Fig-4: Small diameter spinner response in two-phase deviated flow (Courtesy SPE ,Ref 1)

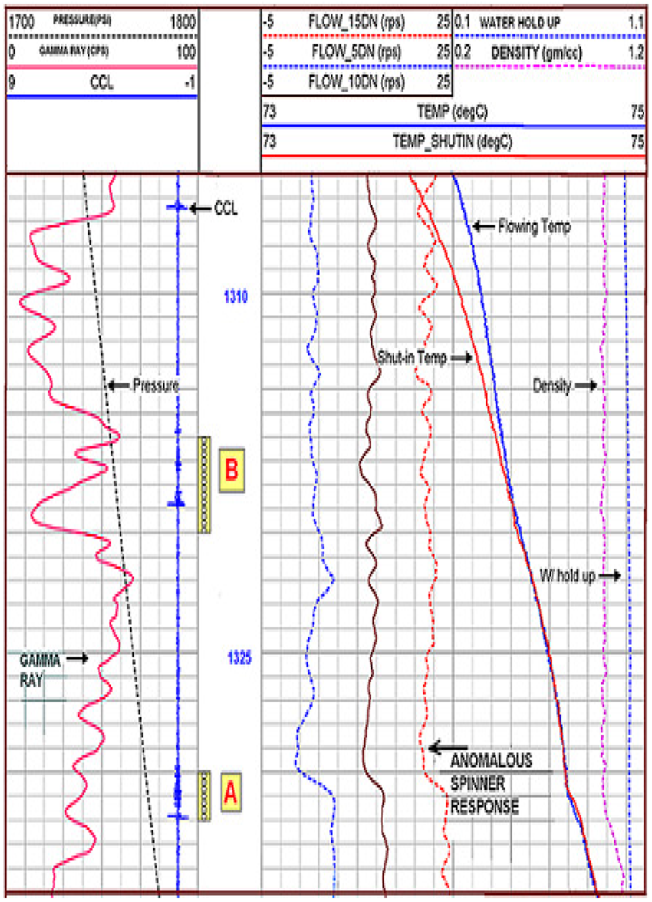

Fig-5: Field example showing anomalous spinner response in Well # X

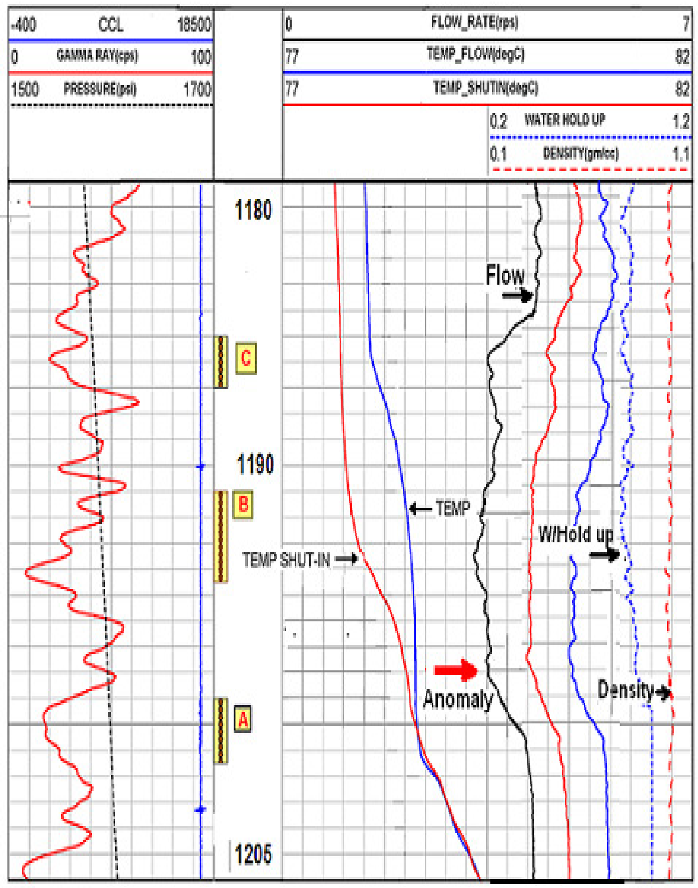

Fig-6: Field example showing unusual flowmeter response in Well#Y