

Real time level, temperature, Quantity and density measurements for petroleum storage tanks

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Abstract—This work presents a cheap ,standard (out of shelf) components real time system to measure the level, Quantity (Liter), Temperature and density of petroleum product in storage tanks based on measuring the Absolut pressure at two points with known distance . The system was designed and implemented based on one PLC , two pressure sensors and PT100 sensor per tank .the system could be used for monitoring N storage tanks simultaneously and reporting to a remote control center where a record is added to the database whenever there is a change in any parameters. The system is operational with accepted result.

Keywords— PLC, DP, GUI, IIR Filter, Web Based, PT100, ADC, RS485, 4-20ma

I. INTRODUCTION

A. Level measurement

Different methods have been used for measuring and monitoring liquid levels. Mechanical float-type depending on up / down movement of a float device placed in the vessel itself. An accurate readings could be obtained but requires frequent calibration and maintenance. An ultrasonic depending on measuring the time required for ultrasound pulses to make around from the sensor to the level although this method avoid direct contact with the fluid, but suffers from inaccuracies causes by varying temperatures and densities in the area above the fluid level and from potential confusion of echoes [1]. Microwave and radar uses low power high frequency impulses and the time difference between transmitted and received impulses to measure the level although more accurate result could be obtained as compared to ultrasound an inaccurate measurements are obtained in fluids with poor dielectric constants. Depending on the operation frequency, the antenna dimensions can limit the minimal distance to the liquid surface to be measured. Even more, all previous methods are electronic in nature so they suffer from intrinsic safety concerns. As with any electronic device, there are necessarily, heat generating Components that create, no matter how remote, the possibility of hazardous situations when used in areas where flammable materials are present. So an extra cost must be considered to make these techniques suitable for inflammable atmospheres with no risk. Optical technologies uses infrared transmitter and receiver with same principle although very good repeatability, hysteresis and response time it is used for transparent liquid and small vessels And wide bandwidth. Different laser and optical instrumentation devices have been already used in level measurement systems, such as

the patent described in [2]. But in any of them the laser, so the electronic driver, is in the sensor head. To avoid electronic presence in the measuring point, optical fibers should be used in the sensor head. This idea has been used in different optical sensors but for measuring short distances or just as simple control level devices [3-4]. A remote sensor head based on optical fibers for long distance is reported in [5] but using different lenses from transmitter and receiver fibers With the complexion related to this disposition, the measuring principle is different and none optical multiplexing is discussed. Differential pressure method based on measuring the pressure difference between two points the level could be obtained when the density is known. DP transmitters are subject to errors due to changes in liquid density. Density variations are caused by temperature changes or change of product. These variations must always be compensated for if accurate measurements are to be made [6].

B. Density Meters

Different methods have been used for measuring and monitoring liquid density. Pythagoras method based on measuring the mass of displaced liquid. Microwave method based on measuring the phase difference between the wave transmitted through drinking water and through the liquid for which the density have to measured Vibrating element method based on measuring the shift in resonance frequency of an element immersed in the liquid which depend on liquid density with temperature compensated method Mass measurement method based on accurate masse measurement for a known volume but none of these are continuous or on-line devices and cannot be considered densitometers. However, discrete measurements such as a pycnometer test are routinely used to prove a densitometer.[7,8].

II. THEORY

A. Level measurement

Using two pressure sensors fixed as shown in Fig. 1 with known distance between the two (D)

$$P = L * \rho * g \quad (1)$$

Where P=Pressure (Pascal) , ρ = Density (Kg/m³)
g = acceleration(m²/s), L = level (m)

$$P1 = L1 * \rho * g \quad (2)$$

$$P2 = L2 * \rho * g \quad (3)$$

$$\frac{P2}{P1} = \frac{L2}{L1} \quad (4)$$

$$L2 - L1 = D \quad (5)$$

So knowing P2 and P1 from sensor reading and D, L2 and L1 could be found .

B. Density measurement

Density could calculate by three ways

$$\rho_1 = \frac{P1}{L1 * g} \tag{6}$$

$$\rho_2 = \frac{P2}{L2 * g} \tag{7}$$

$$\rho_3 = \frac{(P2 - P1)}{(L2 - L1) * g} \tag{8}$$

The final value could be calculated

$$\rho = \frac{(\rho_1 + \rho_2 + \rho_3)}{3} \tag{9}$$

C. Quantity Measurement

- Theoretical calculation

Knowing the theoretical tank geometry (for example cylinder) the quantity Could be calculated as follow

$$Q1 = A * (L2 + D_d) \tag{10}$$

$$Q2 = A * (L1 + D + D_d) \tag{11}$$

The final value

$$Q = \frac{(Q1 + Q2)}{2} \tag{12}$$

Where A=Tank base area=distance between the two sensors , D_d = the distance from bottom to sensor P2 As shown in Fig.1

- Practical approach

A tank calibration table which give the quantity/level step have to be supplied For each tank by an authorized authority. having this table the quantity could be found by using the measured level as an Index in the table to extract the quantity

D. Temperature Measurement

For each PT100 sensor a circuit as shown in Fig.5

Where R-PT100 sensor resistance as a function of temperature, R_{in} =input resistance for ADC card (250 Ohms in this design) , r=cable resistance from sensor to input of ADC,I = current measured by PLC

$$R - PT100 = \frac{5}{I} - r - R_{in} \tag{13}$$

Using a lookup table where the address is the measured resistance and The content is the temperature corresponding to this resistance as given for PT-100 sensor as shown in Fig. 6, the temperature Could be measured with 1C⁰ accuracy

E. Resolution

Level resolution measurement correspond to level calculated when the Output from ADC change by 1 . (for the sensor used in this design the maximum Measured pressure = 2.5 Bar and the maximum digital value for ADC = 16000)

Level Accuracy = [2.5 *100000]/ [16000*9.81*D]

For water the accuracy D= 1000 kg/m³

Level accuracy = 1.5625 mm

Level accuracy = 2.14 mm

Which is comparable to current expensive level meters (radar, ultrasound...)

F. Filter

All measure parameters P2, P1 and temperature are filtered by IIR filter implemented in the PC

$$Y(n) + (1 - \alpha) * X(n) + \alpha * Y(n - 1) \tag{14}$$

A good and stable measurements are obtained using $\alpha \leq 0.1$ with sampling frequency = 10 Hz

III. IMPLEMENTATION

The system implementation as shown in Fig. 2

- modular PLC type with floating point instruction for filters calculation
- ADC (14 Bits (0-16000), 16 channels ADC, 0.5ms conversion time)
- RS485 communication module
- Pressure sensors (2.5 Bar Maximum and 4-20 ma output)
- PC GUI as shown in Fig 3 and for a single tank as shown in Fig 4.
- C# 2010 is used for software for GUI where for each tank Temp, Density, Quantity and Level are displayed
- Three modes of operation are used
 - P2-P1 mode in this mode all the parameters (L2, L1, and Density) are calculated
 - P2-D mode in this mode the density is calculated OFF line and the density Have to be entered as input to the system
 - P1-Mode the same as P2_D using P1 and Density
- SQL Database is used to store the records for each tank containing date,time,L2,L1,Temp and Density Whenever there is a change

IV. CONCLUSION

- Better resolution could be obtained using more than 14 Bits ADC and pressure sensors with less than 2.5 Bar (1.5 Bar) as explained in resolution calculation
- Better accuracy and resolution could be obtained using intelligent pressure sensors with build in processor and compensations to be connected to PC directly through standard protocol(ModBus,Can,RS485,..)
- A web based software could be used to remotely monitoring the system from any browser
- Control and monitoring on the petroleum products in each tank could be easily done based on database
- A more accurate result could be obtained using multi sensors for temperature and density at different tank levels.



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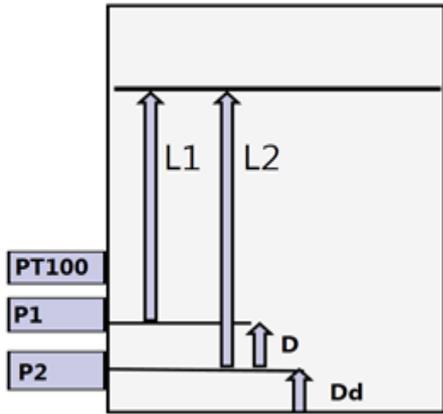


Fig. 1. Pressure and Temperature Sensors

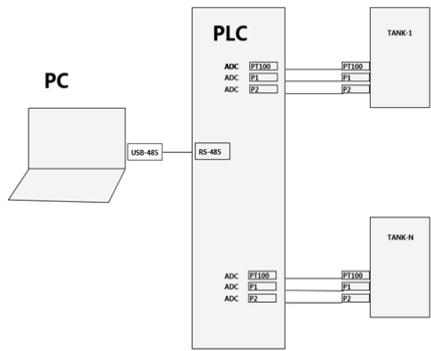


Fig. 2. System Block Diagram

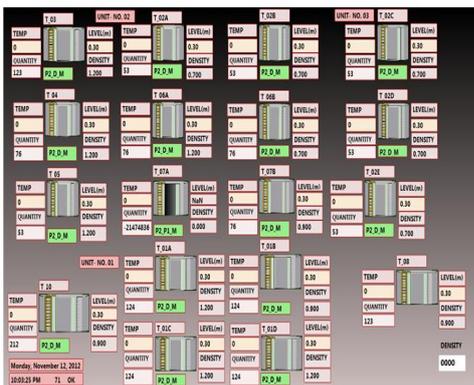


Fig. 3. Graphic User Interface

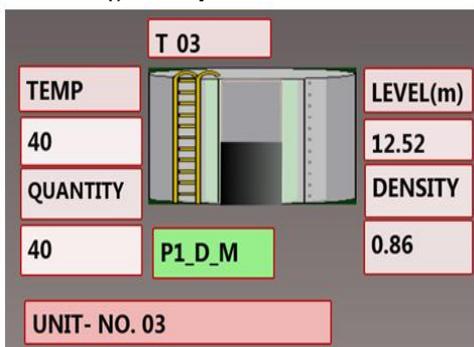


Fig. 4. Single Tank GUI

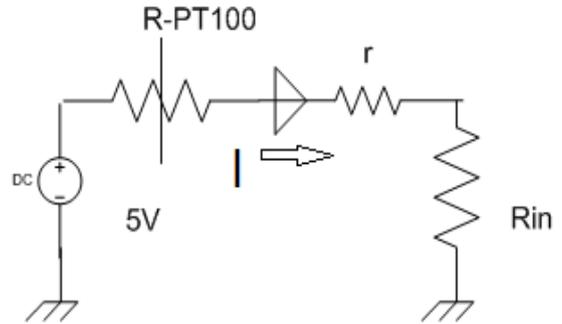


Fig. 5. Temperature Model Calculation

PT100 TEMPERATURE / RESISTANCE TABLE

°C	0	1	2	3	4	5	6	7	8	9	°C
-200	18.8233										18.8233
-190	22.8031	22.3737	21.9439	21.5139	21.0834	20.6526	20.2215	19.7909	19.3598	18.9292	-190
-180	27.0779	26.6280	26.1777	25.7270	25.2759	24.8244	24.3724	23.9200	23.4672	23.0141	-180
-170	31.3200	30.8507	30.3741	29.8901	29.4057	28.9209	28.4357	27.9501	27.4641	26.9777	-170
-160	35.5212	35.0312	34.5344	34.0310	33.5210	33.0044	32.4813	31.9517	31.4156	30.8731	-160
-150	39.7137	39.2067	38.6934	38.1738	37.6478	37.1154	36.5765	36.0312	35.4795	34.9211	-150
-140	43.8981	43.3841	42.8634	42.3360	41.8019	41.2611	40.7136	40.1594	39.5985	39.0311	-140
-130	47.9963	47.4873	46.9724	46.4516	45.9241	45.3899	44.8491	44.3017	43.7477	43.1871	-130
-120	52.0284	51.5232	51.0119	50.4945	49.9709	49.4411	48.9051	48.3627	47.8138	47.2584	-120
-110	56.0033	55.5019	55.0000	54.4975	53.9934	53.4876	52.9801	52.4709	51.9601	51.4477	-110
-100	60.0204	59.5222	59.0271	58.5350	58.0450	57.5571	57.0723	56.5905	56.1117	55.6359	-100
-90	64.2887	63.8000	63.3132	62.8283	62.3454	61.8654	61.3883	60.9141	60.4428	59.9744	-90
-80	68.8261	68.3499	67.8766	67.4061	66.9384	66.4735	66.0113	65.5518	65.0950	64.6409	-80
-70	73.5384	73.0644	72.5927	72.1233	71.6561	71.1920	70.7309	70.2728	69.8177	69.3656	-70
-60	78.3288	77.8569	77.3872	76.9207	76.4573	75.9970	75.5397	75.0854	74.6341	74.1858	-60
-50	83.2004	82.7297	82.2612	81.7950	81.3311	80.8694	80.4108	79.9552	79.5026	79.0529	-50
-40	88.1553	87.6857	87.2182	86.7529	86.2900	85.8294	85.3710	84.9147	84.4604	84.0091	-40
-30	93.1859	92.7173	92.2507	91.7862	91.3238	90.8635	90.4053	89.9491	89.4948	89.0434	-30
-20	98.2924	97.8248	97.3592	96.8957	96.4343	95.9750	95.5178	95.0626	94.6094	94.1591	-20
-10	103.4753	103.0087	102.5441	102.0815	101.6210	101.1625	100.7060	100.2515	99.7990	99.3485	-10
0	108.7350	108.2704	107.8078	107.3473	106.8888	106.4323	105.9778	105.5252	105.0745	104.6257	0
10	114.0716	113.6081	113.1465	112.6869	112.2293	111.7736	111.3198	110.8679	110.4178	109.9694	10
20	119.4843	119.0218	118.5612	118.1026	117.6459	117.1911	116.7381	116.2860	115.8357	115.3872	20
30	124.9724	124.5109	124.0513	123.5937	123.1380	122.6841	122.2319	121.7815	121.3329	120.8861	30
40	130.5453	130.0838	129.6242	129.1666	128.7119	128.2601	127.8101	127.3618	126.9152	126.4703	40
50	136.1924	135.7309	135.2713	134.8147	134.3610	133.9092	133.4592	133.0109	132.5643	132.1194	50
60	141.9127	141.4512	140.9916	140.5340	140.0783	139.6245	139.1725	138.7222	138.2736	137.8266	60
70	147.7044	147.2429	146.7833	146.3257	145.8700	145.4162	144.9642	144.5139	144.0653	143.6183	70
80	153.5667	153.1052	152.6456	152.1879	151.7321	151.2782	150.8261	150.3757	149.9270	149.4799	80
90	159.4988	159.0373	158.5777	158.1190	157.6621	157.2070	156.7536	156.3019	155.8518	155.4032	90
100	165.4999	165.0384	164.5788	164.1201	163.6632	163.2081	162.7547	162.3029	161.8526	161.4038	100
110	171.5692	171.1077	170.6481	170.1894	169.7325	169.2774	168.8239	168.3719	167.9214	167.4724	110
120	177.7049	177.2434	176.7838	176.3251	175.8682	175.4131	174.9596	174.5076	174.0570	173.6078	120
130	183.9052	183.4437	182.9841	182.5254	182.0685	181.6134	181.1599	180.7079	180.2573	179.8081	130
140	190.1691	189.7076	189.2480	188.7893	188.3324	187.8773	187.4238	186.9718	186.5212	186.0720	140
150	196.4946	196.0331	195.5735	195.1148	194.6579	194.2028	193.7493	193.2973	192.8467	192.3974	150
160	202.8807	202.4192	201.9596	201.5009	201.0440	200.5889	200.1354	199.6834	199.2328	198.7836	160
170	209.3264	208.8649	208.4053	207.9466	207.4889	207.0330	206.5788	206.1261	205.6748	205.2249	170
180	215.8307	215.3692	214.9096	214.4509	213.9931	213.5371	213.0828	212.6299	212.1784	211.7283	180
190	222.3926	221.9311	221.4715	221.0128	220.5550	220.0989	219.6444	219.1914	218.7398	218.2896	190
200	229.0111	228.5496	228.0890	227.6293	227.1705	226.7134	226.2579	225.8038	225.3510	224.8996	200
210	235.6852	235.2237	234.7641	234.3054	233.8476	233.3915	232.9370	232.4840	232.0324	231.5821	210
220	242.4137	241.9522	241.4935	241.0357	240.5788	240.1236	239.6700	239.2178	238.7670	238.3176	220
230	249.1956	248.7341	248.2745	247.8158	247.3579	246.9017	246.4471	245.9940	245.5423	245.0920	230
240	256.0299	255.5684	255.1088	254.6501	254.1922	253.7359	253.2811	252.8277	252.3757	251.9250	240
250	262.9156	262.4541	261.9945	261.5358	261.0779	260.6216	260.1668	259.7134	259.2613	258.8104	250
260	269.8517	269.3902	268.9306	268.4719	268.0140	267.5577	267.1028	266.6493	266.1971	265.7462	260
270	276.8374	276.3759	275.9163	275.4576	274.9997	274.5434	274.0885	273.6349	273.1826	272.7316	270
280	283.8727	283.4112	282.9516	282.4929	282.0350	281.5787	281.1238	280.6701	280.2176	279.7664	280
290	290.9566	290.4951	290.0355	289.5768	289.1189	288.6618	288.2064	287.7524	287.2996	286.8480	290
300	298.0891	297.6276	297.1680	296.7093	296.2514	295.7951	295.3401	294.8863	294.4336	293.9820	300
310	305.2694	304.8079	304.3483	303.8896	303.4317	302.9754	302.5204	302.0665	301.6136	301.1617	310
320	312.4957	312.0342	311.5746	311.1159	310.6580	310.2017	309.7468	309.2931	308.8404	308.3886	320
330	319.7670	319.3055	318.8459	318.3872	317.9293	317.4729	317.0178	316.5638	316.1107	315.6586	330
340	327.0823	326.6208	326.1612	325.7025	325.2446	324.7881	324.3329	323.8789	323.4258	322.9736	340
350	334.4406	333.9791	333.5195	333.0608	332.6029	332.1457	331.6891	331.2330	330.7778	330.3234	350

Fig.6 PT-100 Temperature/Resistance Table