THE EFFECT OF DRAG REDUCING AGENTS ON PRESSURE GRADIENT IN MULTIPHASE, OIL/WATER/GAS VERTICAL FLOW.

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ABSTRACT.

Experiments have been carried out in a 20 m long, 10 cm diameter vertical multiphase flow system. The oil used was a light condensate type oil with a viscosity of 2 cP and water cuts of 0 and 50 % were tested. The effect of DRA addition on the pressure gradient in vertical flows for liquid and gas superficial velocities of 0.4 to 2 m/s and 0.5 to 10 m/s was studied at dosages of 0, 10, and 50 ppm.

All the usual flow regimes for vertical flow were observed with churn and bubble flow being present at gas velocities of 1 m/s and lower for all superficial liquid velocities in 100% oil. At superficial gas velocities between 4 and 7 m/s, churn and slug flow existed. For the high gas velocities, annular was the main flow regime. Similar results were noticed for the 50 % water cut except that churn flow was encountered at higher gas velocities.

The average pressure drop and peak to peak fluctuations over 1.9 and 3.8 m were measured and it was found that the average pressure drop increased with increasing superficial liquid velocity for the same superficial gas velocity. The average pressure drop decreased with increasing superficial gas velocities for all cases. The increased void fraction in the flow reduced the density of the flowing mixture and hence the pressure drop due the hydrostatic head.

The addition of DRA had little or no effect on the average pressure drop but the DRA did help "smooth" the flow by reducing the levels of pressure fluctuations.

The DRA is more effective in churn and slug flow where a DRA concentration of 50 ppm produces a much larger decrease in the pressure fluctuations. However, some benefit was seen at 10 ppm of DRA.

In bubble flows, only are small reductions in the peak to peak fluctuations are noted.

The DRA does not seem effective at the high superficial liquid velocity where the hydrostatic head is very large. Also the DRA also was not effective at high superficial gas velocities when annular flow was present.

1. INTRODUCTION.

Previous work has been carried out in horizontal and inclined pipelines to examine the effect of the addition of drag reducing agents on pressure gradient in both single phase liquid and multiphase oil/water/gas systems. It was found that the drag reducing agents not only affected the frictional pressure drop but also could change the nature of the flow and flow regime. This led to several possible extended uses for DRA's. These results have been submitted in earlier reports.

It has been suggested that DRA's can have little effect in vertical single phase flows since the majority of the pressure gradient is due to the hydrostatic head of the vertical column of liquid. From the results of the multiphase flow studies in inclined pipes, it was found that by changing the flow regime and other flow characteristics such as slug frequency, etc., the DRA could be effective where it would not normally be expected to do so.

The production from wells involves multiphase flow in vertical pipes and significant benefits could be gained if the pressure gradient could be reducing in these situations.
It is important to ascertain if DRA's can provide any benefit.

This work examines the effect of DRA addition on the pressure gradient in vertical flows for liquid and gas superficial velocities of 0.4 to 2 m/s and 0.5 to 10 m/s respectively. A light condensate type oil was used at water cuts of 0 and 50 %. The tests were carried out in a 10 cm diameter flow system.

2. EXPERIMENTAL SETUP.

The layout of the experimental flow loop is shown in Figure 1. The specified composition of the oil-water mixture is placed in a 1.2 m^3 stainless steel storage tank (A). The tank is equipped with 6 m (2.5cm ID) stainless steel cooling coils to maintain a constant temperature.. The oil-water mixture is then pumped into a 10.16 cm ID PVC pipeline using a 76 hp stainless steel, Moyno progressing cavity pump (C). Carbon dioxide from 25 ton tanks is introduced into the system and the gas flow rate is measured using a variable area flow meter. The multiphase mixture then flows through 3.1 m long flexible hose (10.16 cm ID) and into a 20 m long inclined plexiglass pipeline (10.16cm ID).

The pressure drop along 1.9 and 3.8 m length of the pipeline is measured using the pressure tappings (F) connected to A-5/882-12 Sensotec pressure transducers. The response is taken to a 586 PC where the average pressure and pressure fluctuations are determined.

The flow then returns into the storage tank where the liquid is recycled and the gas vented to atmosphere.

Initially, experiments were carried out with no drag reducing agent present. These provided the baseline values for the pressure and fluctuations. Then, 10 ppm of drag reducing agent was added and the experiments repeated. Finally, 50 ppm of DRA was used.

Two oil/water compositions were tested. These were 0 and 50 % water cut. The test matrix is given below.

At the beginning of each DRA addition, the change in pressure with time was noted. This was to ascertain if the DRA was being degraded by the pump or system. There was no change in the pressure results with time which did indicate that the DRA was not degraded substantially.

Videos of all the experiments were taken to visually examine the flow regime and the flow characteristics. An edited version is enclosed with this report.

2. 1. Test Matrix

Table 1 shows the test matrix for this study. LVT 200 with a viscosity of 2 centipoise and a density of 800 kg/m^3 is used as the oil. Carbon dioxide is used as the gas.

Inclination	90 Degree Upward
Drag Reducing Agent	CDR Liquid Power
DRA Concentration, ppm	0, 10, 50
Pressure, MPa	0.13
Oil Tested	Conoco LVT 200
Water cut %	0, 50
Gas Flow Velocity, m/s	0.5, 1.0, 4.0, 7.0, 10
Liquid Flow Velocity, m/s	0.4, 1.0, 1.5, 2.0

Table 1 Test Matrix for the Study

3. RESULTS.

For all the experiments, the nature of the flow and the corresponding characteristics were monitored. The flow regimes are described below.

3.1 Flow Regime.

It should be noted that the flow regimes in vertical pipes are very different from those in horizontal and slightly inclined pipelines. Dispersed flow in the form of bubble flow is present over a wide range of liquid flows at low gas velocities. Further, the intermittent regimes are very common at intermediate gas velocities. These include both churn and slug flows. The former involves the pulsations of liquid moving up and then down the pipe with gas being entrained. The latter has gas pockets which help carry the liquid slugs upward and the only backflow occurs in the liquid film at the pipe wall when the gas pocket passes. Both of these flow regimes has associated high values of pressure gradient caused by these fluctuations. Much of this pressure loss cannot be recovered. At high gas velocities, annular flow is present and this is very similar to that in horizontal flows.

From examination of the videos, the flow regimes were determined at each condition. The results are presented in Tables 2 and 3.

For 100% LVT oil, Table 2 shows that at low superficial liquid and gas velocities of 0.4 m/s and 0.5 m/s respectively, bubble flow together with an intermittent churn flow was observed for DRA compositions of 0, 10, and 50 ppm. Similar results ere noticed for a superficial gas velocity of 1.0 m/s at 0 and 10 ppm DRA. However, with 50 ppm of DRA bubble flow disappeared leaving only churn flow.

At the higher superficial gas velocities, bubble flow was not observed for all concentrations of DRA and churn flow was dominant. At a superficial gas velocity of 10 m/s, the flow regime changed from churn to annular for all concentrations of DRA.

As the superficial liquid velocity was increased to 1.0 m/s, similar observations were obtained at the low superficial gas velocities of 0.5 m/s and 1.0 m/s. Increasing the superficial gas velocity to 4.0 m/s, slug flow was noticed for 0 ppm and 10 ppm DRA. However, at a higher DRA concentration of 50 ppm, no slug flow was observed and only churn flow was noticed. Churn flow persisted with increasing superficial gas velocity to 7.0 m/s for 0 ppm and 10 ppm DRA. At 50 ppm DRA, the flow regime was changed from churn to annular. Annular flow was observed for all conditions of DRA at the high superficial gas velocity of 10.0 m/s.

At a superficial liquid velocity of 1.5 m/s and a low superficial gas velocity of 0.5 m/s, bubble and churn flow was observed for all concentrations of DRA. At 1.0 m/s superficial gas velocity, churn flow was observed for 0 ppm DRA. This was accompanied by slug flow for 10 ppm DRA and bubble flow for 50 ppm DRA. At a superficial gas velocity of 4.0 m/s, slug flow was observed for all DRA concentrations. Higher gas flow rates of 7.0 m/s and 10.0 m/s saw the appearance of annular flow for all cases.

At the highest superficial liquid velocity of 2.0 m/s, bubble flow dominated for all conditions of DRA for low superficial gas velocities of 0.5 m/s and 1.0 m/s. Higher superficial gas velocity of 4.0 m/s gave slug flow for 0 ppm and 10 ppm DRA while annular flow was seen for 50 ppm DRA. Annular flow became dominant for all other superficial gas velocities and DRA concentrations.

The effect of increasing water cut to 50 % on flow regime is given in Table 3. The results are very similar to those described above. However, slug flow was more noticeable at the higher superficial liquid velocity of 2 m/s.

Clearly form these Tables, the addition of 10 ppm of DRA does not affect the flow regime. However, 50 ppm of DRA can change the flow regime from churn to annular and slug to annular. This has a great benefit since the pressure gradient and corresponding fluctuations are usually much lower in annular flow than the intermittent churn and slug flows.

3.2 Pressure Drop.

The pressure drop over both 1.9 and 3.8 m long sections of the pipeline was measured at each flowing condition . Typical responses of the pressure drop across the 3.8 m long section are presented in Figures 2 to 28. Similar results were obtained for both the 1.9 and 3.8 m sections.

In each case, there are fluctuations in the pressure around an average value due to the passage of bubbles in bubble flow, the upward and downward pulsations of the liquid in churn flow, the intermittent gas pockets in slug flow, and the presence of waves in annular flow.

Each response is analyzed to obtain the average pressure drop and the magnitude of the fluctuations in the pressure.

3.2.1. Average Pressure Drop.

The average pressure drop for 100% LVT oil and for a water cut of 50 % are given in Tables 4 and 5. It is noted that for each liquid velocity, the pressure drop decreases with an increase in the gas velocity. For example, for 100 % oil at a liquid superficial velocity of 1.0 m/s, Table 4 shows the average pressure drop over 3.8 m decreases from 21800 to 7600 Pa as the gas velocity is increased from 0.5 to 10 m/s. This occurs for several reasons. Firstly, increasing the gas velocity leads to a higher insitu void fraction and a subsequent decrease in the average density of the multiphase flow. The pressure drop due to the hydrostatic head is therefore reduced. Secondly, the flow regime changes from bubble to churn and then annular flow with increase in gas velocity. The more intermittent type flows, slug and churn, do have a higher associated pressure drop than that in annular flow.

When DRA is added to the flow, there seems little change in the average pressure drop. For DRA concentrations of 0 ppm, 10 ppm, and 50 ppm at superficial liquid and superficial gas velocities of 0.4 m/s and 4 m/s respectively, the pressure drops are 6400, 6450, and 6300 Pa respectively. At superficial liquid and superficial gas velocities of 1.5 m/s and 7 m/s, values of 10100, 10000, and 10100 Pa are measured for 0, 10, and 50 ppm DRA.

At 50 % water cut, Table 5 indicates similar results. Here, since the water has a higher density, the pressure drop in each case is higher than for 100 % oil. Comparing Tables 4 and 5 shows that for a superficial gas velocity of 0.5 m/s, the average pressure drop increases from 19100 Pa to 25800 Pa by increasing the superficial liquid velocity from 0.4 to 2.0 m/s. For the 50% water cut, the average pressure drop increases from 22900 to 28400 Pa for the respective liquid velocities.

3.2.2. Pressure Fluctuations.

It was shown above that the DRA did not have much effect on the average pressure drop. However, the DRA was effective in reducing the fluctuations in the pressure. This indicates that the DRA is acting to change the nature of the flow by smoothing out the pulsations and waves present in the different flow regimes.

Figures 2 to 28 provide the information on the magnitude and frequency of the pressure fluctuations.

Figures 2 plots the fluctuation for 100 % oil at 0 ppm DRA at superficial liquid and gas velocities of 0.4 and 4 m/s respectively. It can be seen that the fluctuation in the pressure varies from

3200 to 9400 Pa. There are localized values as low as 1500 and as high as 10800 Pa. The average peak to peak fluctuation is approximately 6200 Pa. The peaks correspond to the pulsations in the flow. Table 1 indicates that churn flow exists at these conditions. Here, the liquid does have a net flow upward but there are pulses of liquid that initially move up followed by a backward motion. The frequency of these pulses is about 1.6 pulses per second (16 over a ten second period).

When 10 ppm of DRA is added, Figure 3 indicates that the peak to peak fluctuation decreases from 6200 to 5200 Pa showing that the flow is "smoother". The frequency of the pulses still remains the same at 1.5 per second.

A more dramatic change is noted when 50 ppm of DRA is added. Figure 4 shows the fluctuations have decreased from 6200 to 4600 Pa. It is also noticed that the pulsations are all of the same magnitude. There are no longer cases where very large fluctuations occur. The percentage fluctuation reduction with 10 and 50 ppm is 16 and 26 % respectively.

As the superficial liquid velocity is increased to 1 m/s with a superficial gas velocity of 4 m/s Figure 5 shows that for 0 ppm DRA, the fluctuations are much larger. This is partly due to the presence of slug flow at these conditions. The fluctuations now range between 7200 and 15100 Pa. The peak to peak fluctuation being approximately 7900 Pa. Again, there are much larger localized values. The flow is still churn flow and the frequency has increased to approximately 2 per second.

Figures 6 and 7 indicate that the addition of 10 and 50 ppm DRA again reduces the magnitude of the fluctuations with the 50 ppm dose having the greatest effect. The slug flow has been removed and churn flow exists. The reductions are from 7900 to 6900 Pa and from 7900 to 6000 Pa for the 10 and 50 ppm DRA respectively corresponding to 13 and 25%.

Similar results are presented in Figures 8, 9, and 10 for a superficial liquid velocity of 1.5 m/s and superficial gas velocity of 4 m/s. The flow regime for 0 and 10 ppm DRA was slug and churn flow with the corresponding large fluctuations of approximately 9000 Pa. At 50 ppm of DRA, no slug flow was observed and a significant reduction in the fluctuations were noted. At 10 and 50 ppm, the fluctuations are reduced from 8700 to 8100 Pa and from 8700 to 5600 Pa respectively. The fluctuation reduction with 50 ppm DRA is above 35%.

As the gas velocity is increased to 10 m/s at the liquid velocity of 1.5 m/s, annular flow is present. Figures 11, 12 and 13 show that the peak to peak fluctuations were about 10700 Pa. At this high liquid flowrate, there are probably large waves or pseudo-slugs propagating on the liquid film next to the pipe wall. The frequency of these is approximately 2.4 per second. The addition of DRA at both 10 and 50 ppm has little or no affect on the flow and the fluctuations.

For the highest liquid velocity of 2 m/s and a superficial gas velocity of 1 m/s, a mixture of bubble, churn, and slug flow was observed. The pressure fluctuations are presented in Figures 14, 15, and 16. The frequency of the bubbles, pulsations, waves, etc. are now much higher at 3.5 per second. The fluctuations are again reduced from 3300 to 2750 Pa and from 3300 to 2200 Pa with the addition of 10 and 50 ppm DRA respectively. The fluctuation reduction with 50 ppm is 33%.

Figures 17 to 28 give the corresponding plots of pressure for the 50 % water cut. Results similar to that of the 100 % oil were obtained except that the average pressure and the corresponding fluctuations were greater for the 50 % water cut than the oil alone.

For 0 ppm DRA, comparing Figures 2 and 17 show that for superficial liquid and gas velocities of 0.4 and 4 m/s, the peak to peak fluctuations for the 50 % water cut were 8900 Pa but only 6200 Pa for the 100 % oil. Further, the frequency of the pulsations was higher for the 50 % water cut at about 2.6 per second.

Figures 18 and 19 give the fluctuations with 10 and 50 ppm DRA. It is seen that a small reduction from 8900 to 8300 Pa at 10 ppm DRA whilst for 50 ppm, a reduction from 8900 to 7100 Pa is noted.

Figures 20 to 28 are provided for completeness but are not discussed in detail here.

A fuller picture can be obtained by examining Figures 29 to 36. These show the effect of the DRA addition on the peak to peak pressure fluctuations with increasing gas velocity.

For 100 % oil at a liquid velocity of 0.4 m/s, Figure 29 indicates that the pressure fluctuations can be reduced by the addition of DRA for gas velocities up to about 7 m/s. At the low gas velocities of 0.5 and 1 m/s where bubble flow occurs, adding DRA leads small reductions of about 300 and 500 Pa at 10 and 50 ppm respectively. At a gas velocity of 4 m/s where churn flow exists, the reductions are much greater with about 1000 and 1500 Pa being achieved at 10 and 50 ppm DRA. Above a ga velocity of 7 m/s, annular flow is present. Here, little or no benefit is achieved from the DRA.

Similar results are seen in Figures 31 and 32 for superficial liquid velocities of 1 and 1.5 m/s. The exceptions being at a liquid velocity of 1 m/s and t a gas velocity of 7 m/s, the DRA does reduce the fluctuations substantially. Here, churn flow still exists and annular flow has not been reached except at 50 ppm DRA. Further, at a liquid velocity of 1.5 m/s and a gas velocity of 1 m/s where slug flow is present, the fluctuations are again reduced significantly.

At the highest liquid velocity of 2 m/s, the DRA was only effective in reducing the fluctuations at low gas velocities where bubble and churn flows were present.

The equivalent results for 50 % water cut are presented in Figures 33 to 37. Very similar observations were made except that the DRA was effective in reducing the fluctuations at higher gas velocities. Here, churn and slug flow were more apparent for the 50 % water cut than the 100% oil.

4. CONCLUSIONS

All the usual flow regimes for vertical flow were observed.

Churn and bubble flow were present at gas velocities of 1 m/s and lower for all superficial liquid velocities in 100% LVT oil. At superficial gas velocities between 4 and 7 m/s, churn and slug flow existed. For the high gas velocities, annular was the main flow regime.

For the 50 % water cut, churn flow was encountered at higher gas velocities.

From the pressure responses both the average pressure drop and peak to peak fluctuations over 1.9 and 3.8 m were measured. The following was found.

The average pressure drop increased with increasing superficial liquid velocity for the same superficial gas velocity. This is due to the increase in the volume of the liquid in pipe as the superficial liquid velocity increases.

The average pressure drop decreased with increasing superficial gas velocities for all cases. The increased void fraction in the flow reduced the density of the flowing mixture and hence the pressure drop due the hydrostatic head.

The addition of DRA had little or no effect on the average pressure drop.

DRA did help "smooth" the flow by reducing the levels of pressure fluctuations.

The DRA is more effective in churn and slug flow where a DRA concentration of 50 ppm produces a much larger decrease in the pressure fluctuations. However, some benefit was seen at 10 ppm of DRA.

There are small reductions in bubble flows.

The DRA does not seem effective at the high superficial liquid velocity where the hydrostatic head is very large.

The DRA also was not effective at high superficial gas velocities when annular flow was present.

Table 2. Flow Regime vs. % of DRA in 100% LVT Oil in 90 Degree Inclination

Val.	V.G.	Flow Regime		
m/s	m/s	0 ppm	10 ppm	50 ppm
0.4	0.5	bubble + churn	bubble + churn	bubble + churn
0.4	1	bubble + churn	bubble + churn	churn
0.4	4	churn	churn	churn
0.4	7	churn	churn	churn
0.5	10	annular	annular	annular
1.0	0.5	bubble + churn	bubble + churn	bubble + churn
1.0	1	bubble + churn	bubble + churn	bubble + churn
1.0	4	churn + slug	churn + slug	churn
1.0	7	churn	churn	annular
1.0	10	annular	annular	annular
1.5	0.5	bubble + churn	bubble + churn	bubble + churn
1.5	1	churn	churn + slug	churn + bubble
1.5	4	slug	slug	churn + slug
1.5	7	annular	annular	annular
1.5	10	annular	annular	annular
2.0	0.5	bubble	bubble	bubble
2.0	1	bubble	bubble	bubble + churn
2.0	4	slug	slug	annular
2.0	7	annular	annular	annular
2.0	10	annular	annular	annular

Table 3. Flow Regime vs. % of DRA in 50% LVT Oil-50% Water in 90 Degree Inclination

Val.	V.G.	Flow Regime		
m/s	m/s	0 ppm	10 ppm	50 ppm
0.4	0.5	bubble + churn	bubble + churn	bubble + churn
0.4	1	bubble + churn	bubble + churn	bubble + churn
0.4	4	churn	churn	churn
0.4	7	churn	churn	churn
0.5	10	annular	annular	annular
1.0	0.5	bubble + churn	bubble + churn	bubble + churn
1.0	1	bubble + churn	bubble + churn	bubble + churn
1.0	4	churn + slug	churn	churn
1.0	7	churn	churn	annular
1.0	10	annular	annular	annular
1.5	0.5	bubble + churn	bubble + churn	bubble + churn
1.5	1	churn + bu + slug	churn + bu + slug	bubble + churn
1.5	4	churn + slug	churn + slug	slug
1.5	7	annular	annular	annular
1.5	10	annular	annular	annular
2.0	0.5	churn + bu + slug	bubble	bubble
2.0	1	churn + bu + slug	churn + bu + slug	churn + bu + slug
2.0	4	churn + slug	annular	annular
2.0	7	annular	annular	annular
2.0	10	annular	annular	annular

Table 4. Average Pressure Drop vs. % of DRA in 100% LVT Oil in 90 Degree Inclination

Val.	V.G.	Average Pressure Drop		
		0 ppm	10 ppm	50 ppm
m/s	m/s	Pa	Pa	Pa
0.4	0.5	19100	19300	19400
0.4	1	16100	15900	16400
0.4	4	6400	6450	6300
0.4	7	3900	3850	3900
0.4	10	3250	3350	3350
1.0	0.5	21800	21600	21900
1.0	1	18100	18200	18150
1.0	4	11000	10900	10850
1.0	7	7800	7900	7900
1.0	10	7600	7600	7700
1.5	0.5	22600	22900	22700
1.5	1	21800	21800	21900
1.5	4	13300	13300	13400
1.5	7	10100	10000	10100
1.5	10	10200	10200	10100
2.0	0.5	25800	15600	25900
2.0	1	25200	25250	25150
2.0	4	15700	15500	15700
2.0	7	12800	12700	12900
2.0	10	12300	12300	12300

Table 5. Average Pressure Drop vs. % of DRA in 50% LVT Oil-50% Water in 90 Degree Inclination

Val.	V.G.	Average Pressure Drop		
		0 ppm	10 ppm	50 ppm
m/s	m/s	Pa	Pa	Pa
0.4	0.5	22900	22700	23100
0.4	1	18500	18550	18700
0.4	4	7300	7200	7500
0.4	7	5050	4950	5200
0.4	10	4270	4300	4350
1.0	0.5	25300	25100	25600
1.0	1	21700	21600	21900
1.0	4	12250	12000	12000
1.0	7	9100	9200	9200
1.0	10	8600	8600	8750
1.5	0.5	26900	26800	27100
1.5	1	24600	24700	24900
1.5	4	16400	16250	16500
1.5	7	11900	11800	11900
1.5	10	11500	11750	11800
2.0	0.5	28400	28400	28700
2.0	1	26950	26750	27100
2.0	4	17800	17850	16500
2.0	7	14800	14750	15000
2.0	10	14800	14800	14850

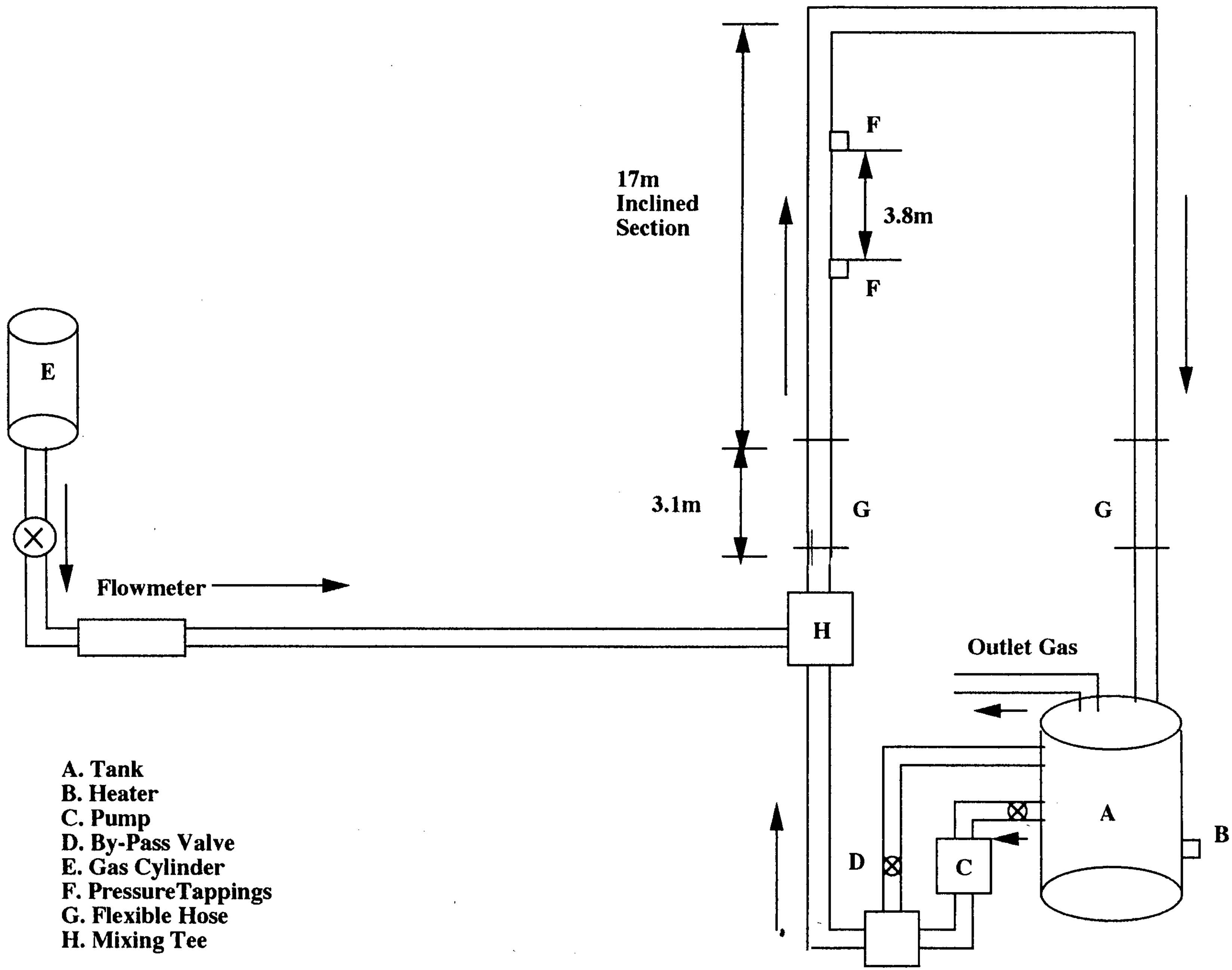


Figure 1 : Experimental layout of the flow loop

Figure 2. 100% LVT, 0 ppm, Vsl = 0.4 m/s, Vsg = 4 m/s

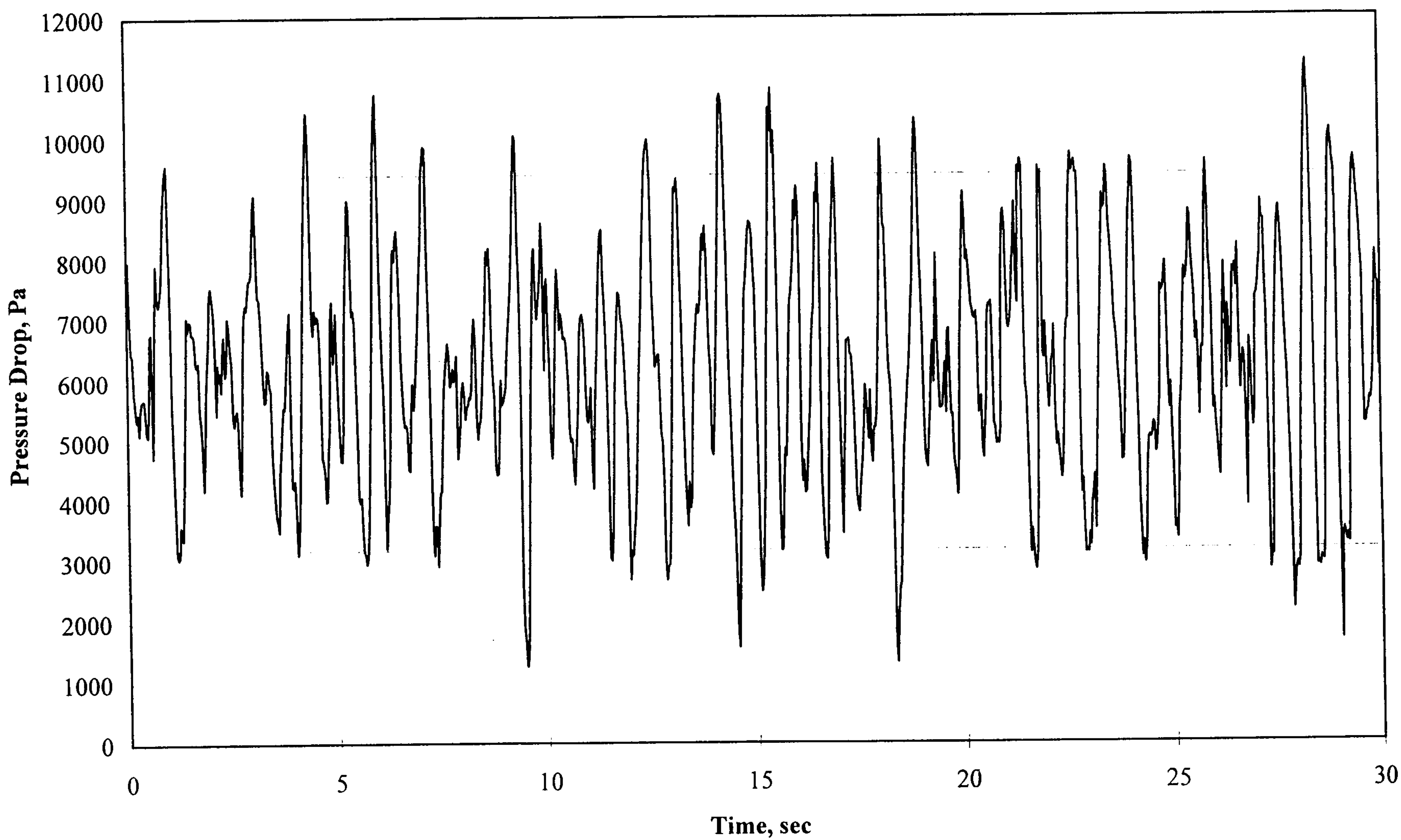


Figure 3. 100% LVT, 10 ppm, Vsl = 0.4 m/s, Vsg = 4 m/s

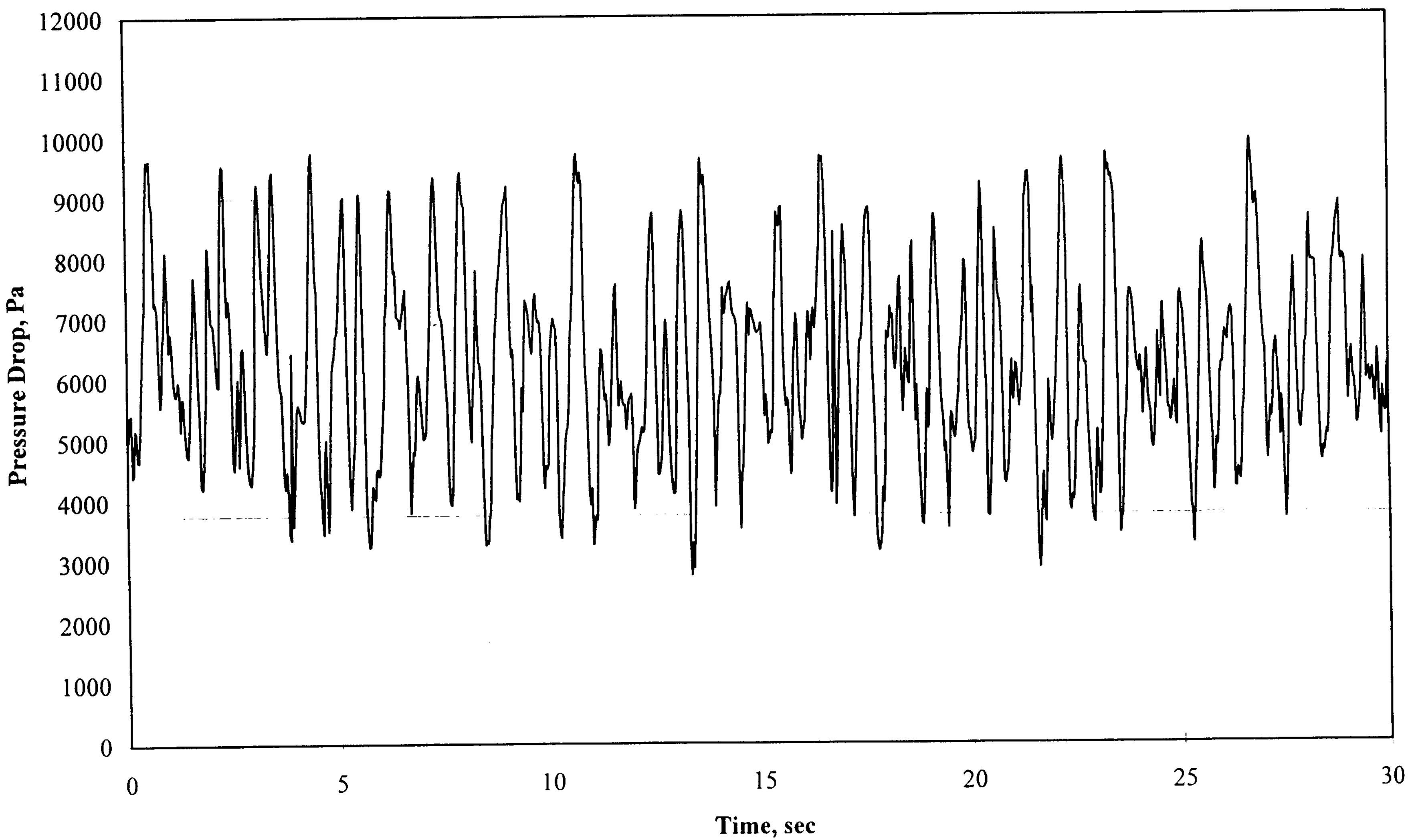


Figure 4. 100% LVT, 50 ppm, Vsl = 0.4 m/s, Vsg = 4 m/s

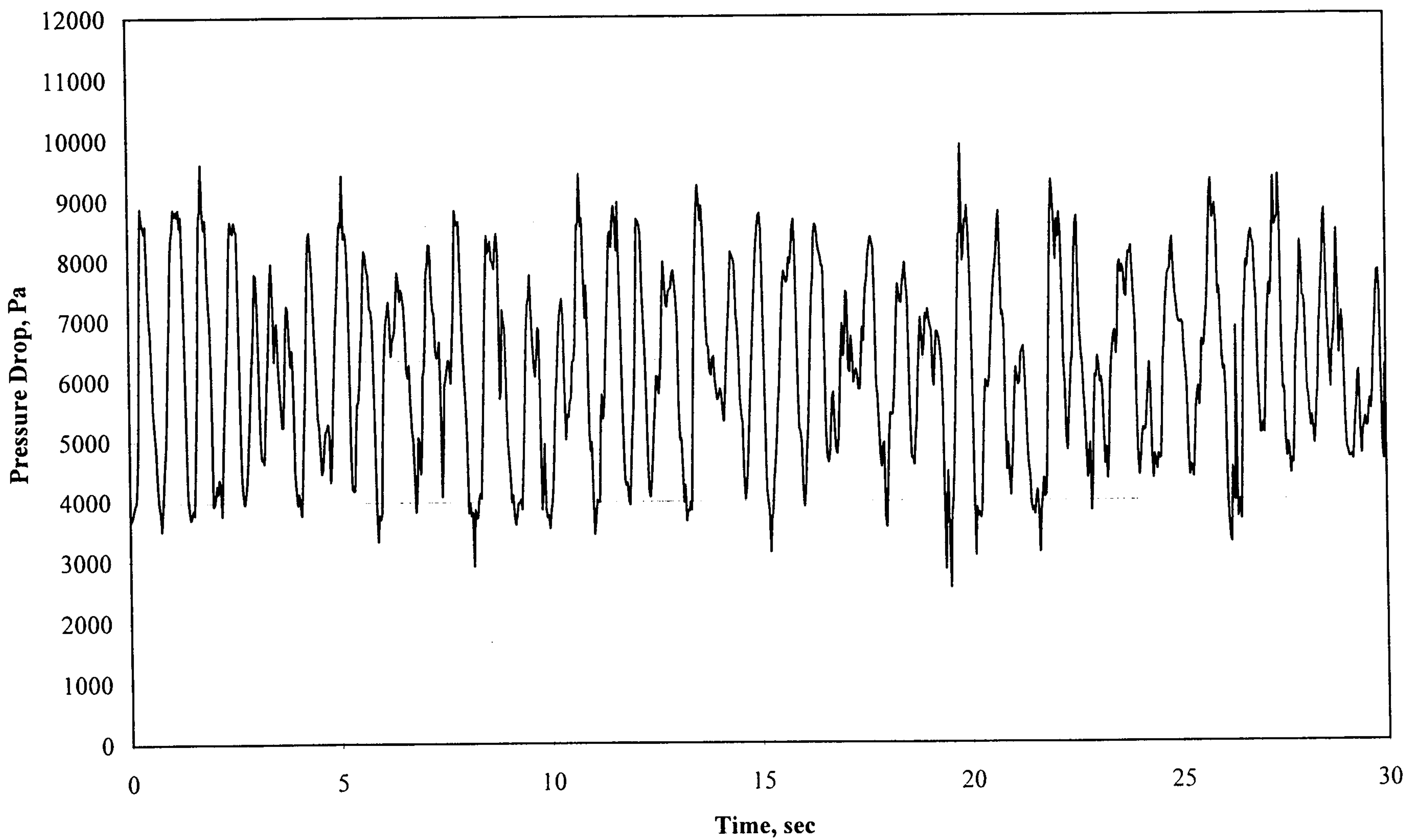


Figure 5. 100% LVT, 0 ppm, Vsl = 1 m/s, Vsg = 4 m/s

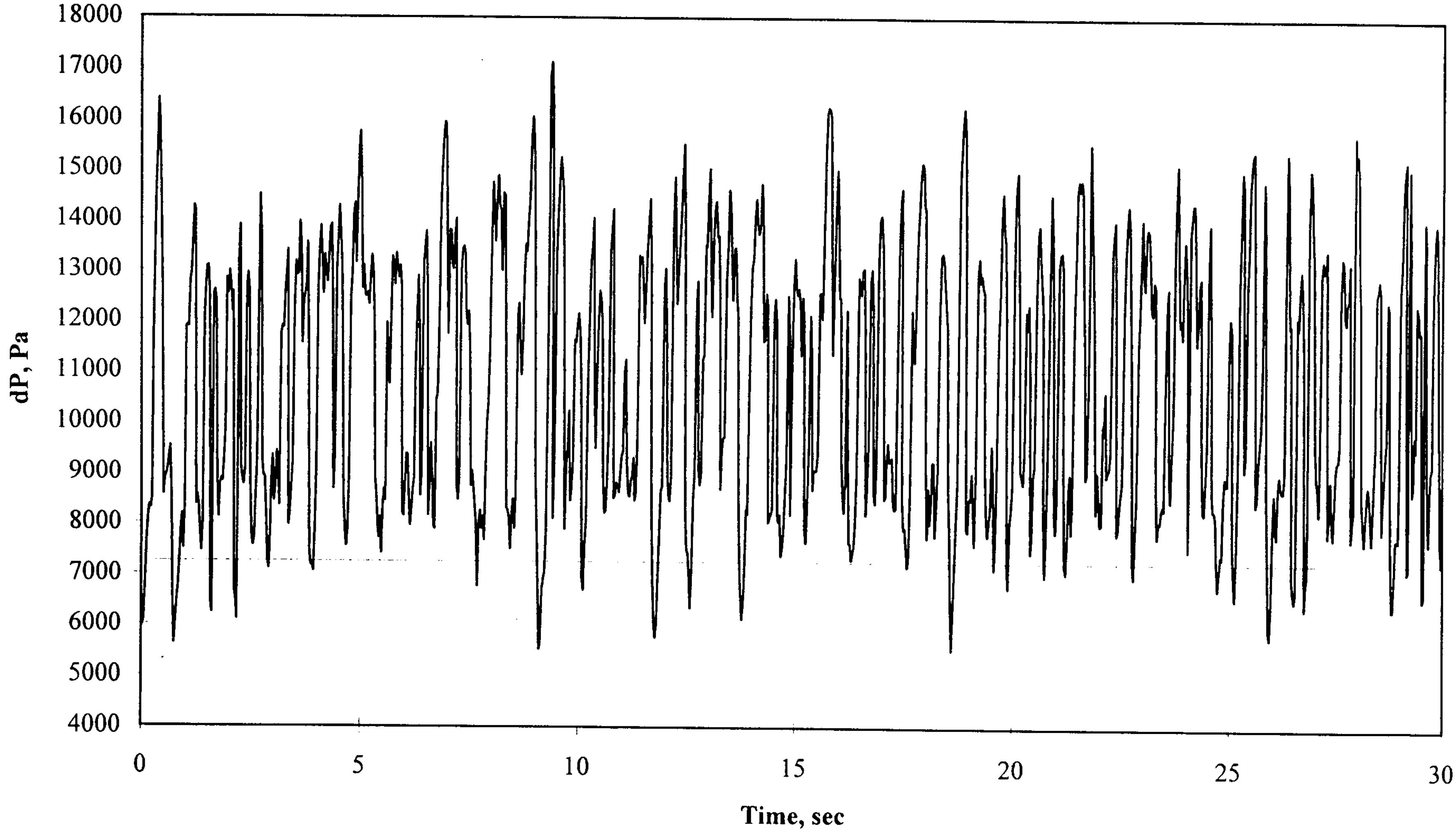


Figure 6. 100% LVT, 10 ppm, Vsl = 1 m/s, Vsg = 4 m/s

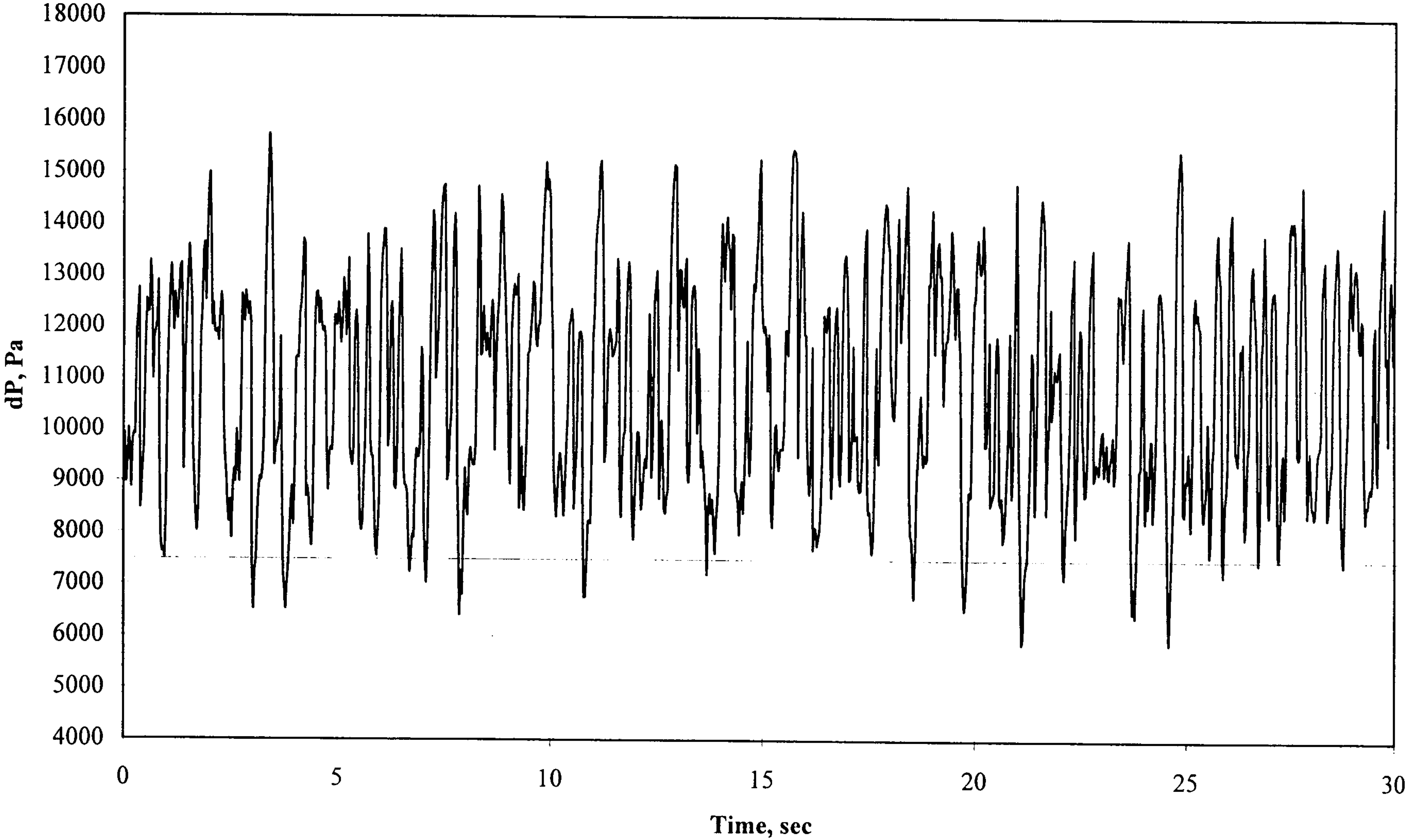


Figure 7. 100% LVT, 50 ppm, Vsl = 1 m/s, Vsg = 4 m/s

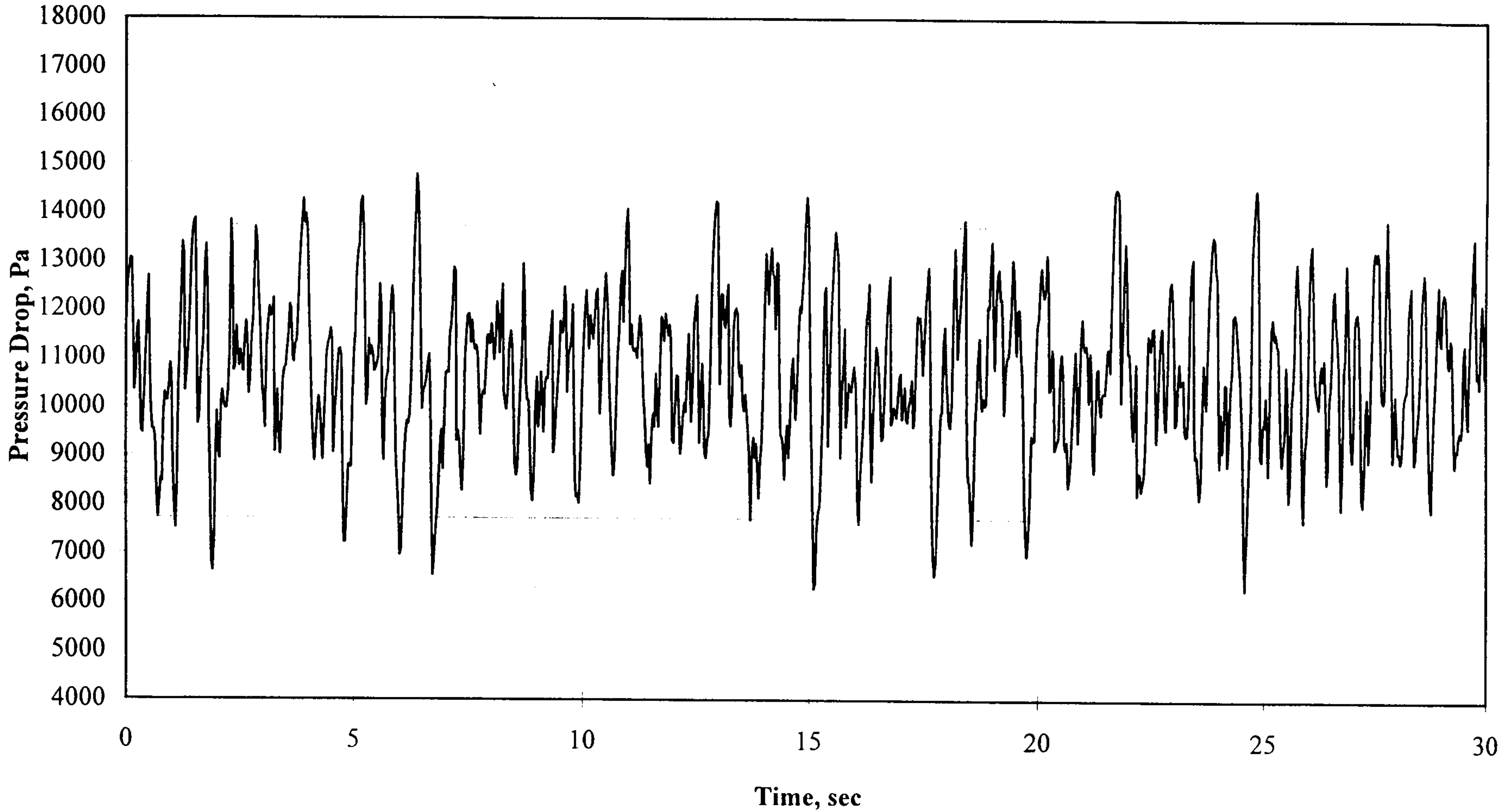


Figure 8. 100% LVT, 0 ppm, Vsl = 1.5 m/s, Vsg = 4 m/s

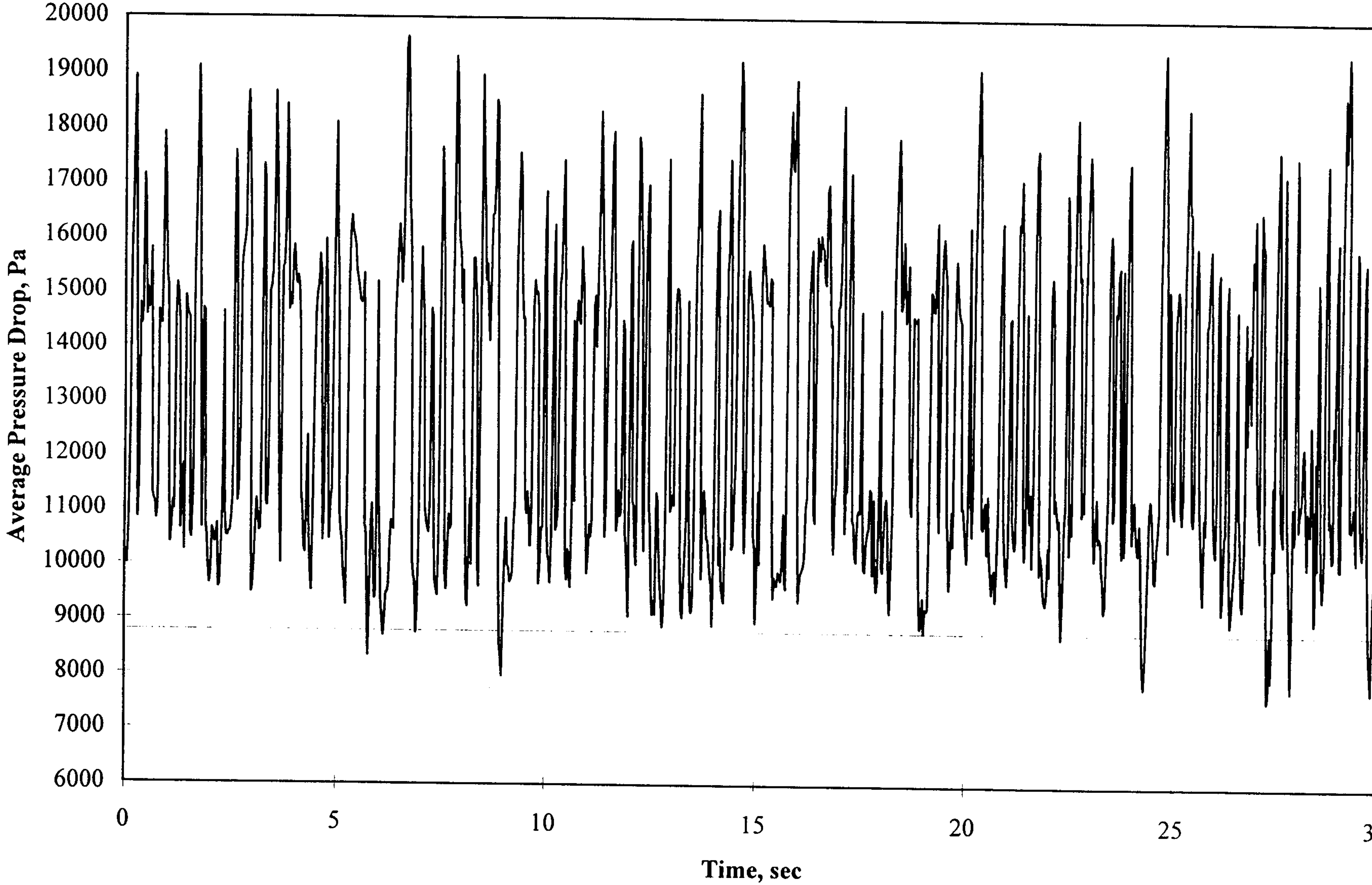


Figure 9. 100% LVT, 10 ppm, Vsl = 1.5 m/s, Vsg = 4 m/s

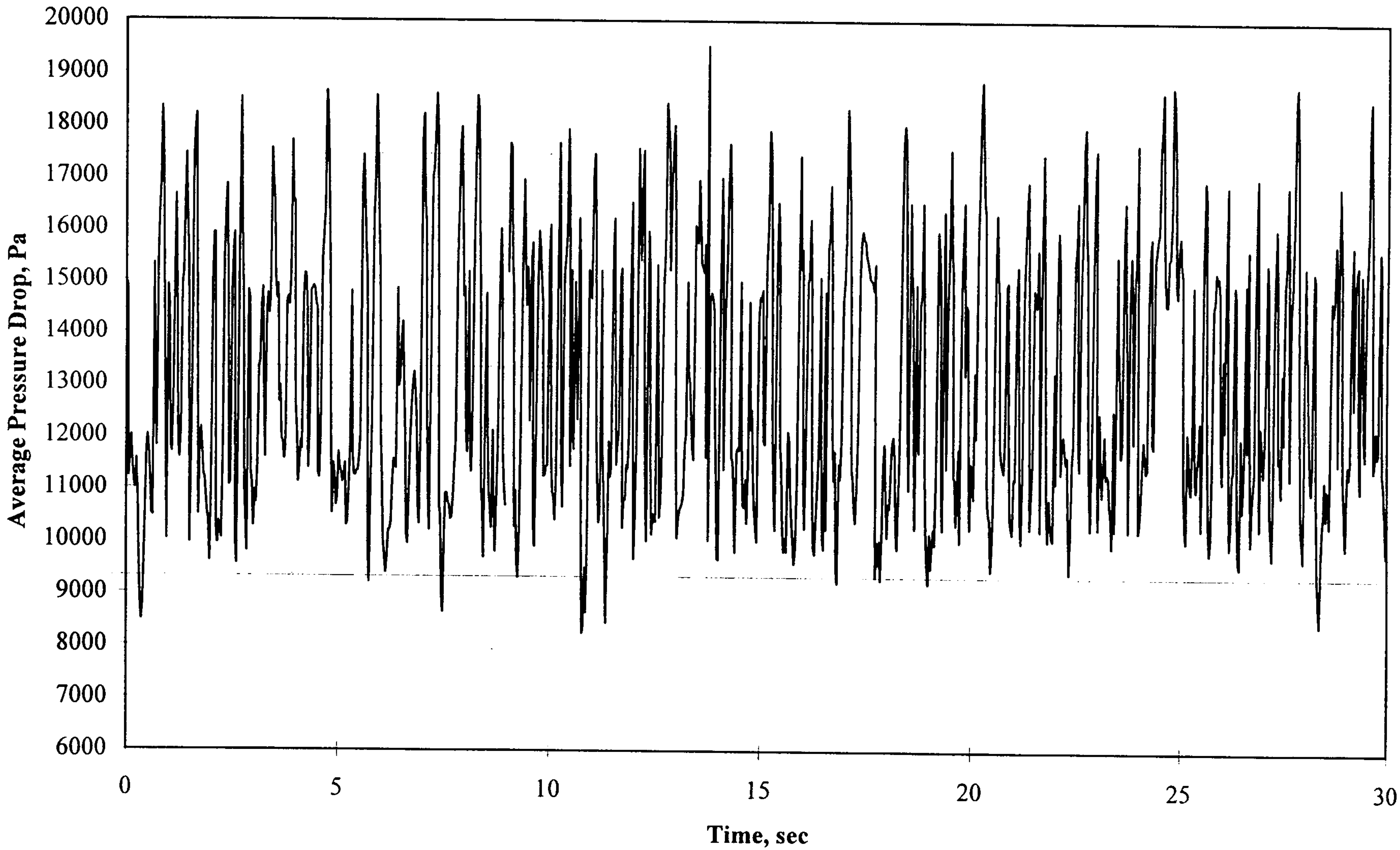


Figure 10. 100% LVT, 50 ppm, Vsl = 1.5 m/s, Vsg = 4 m/s

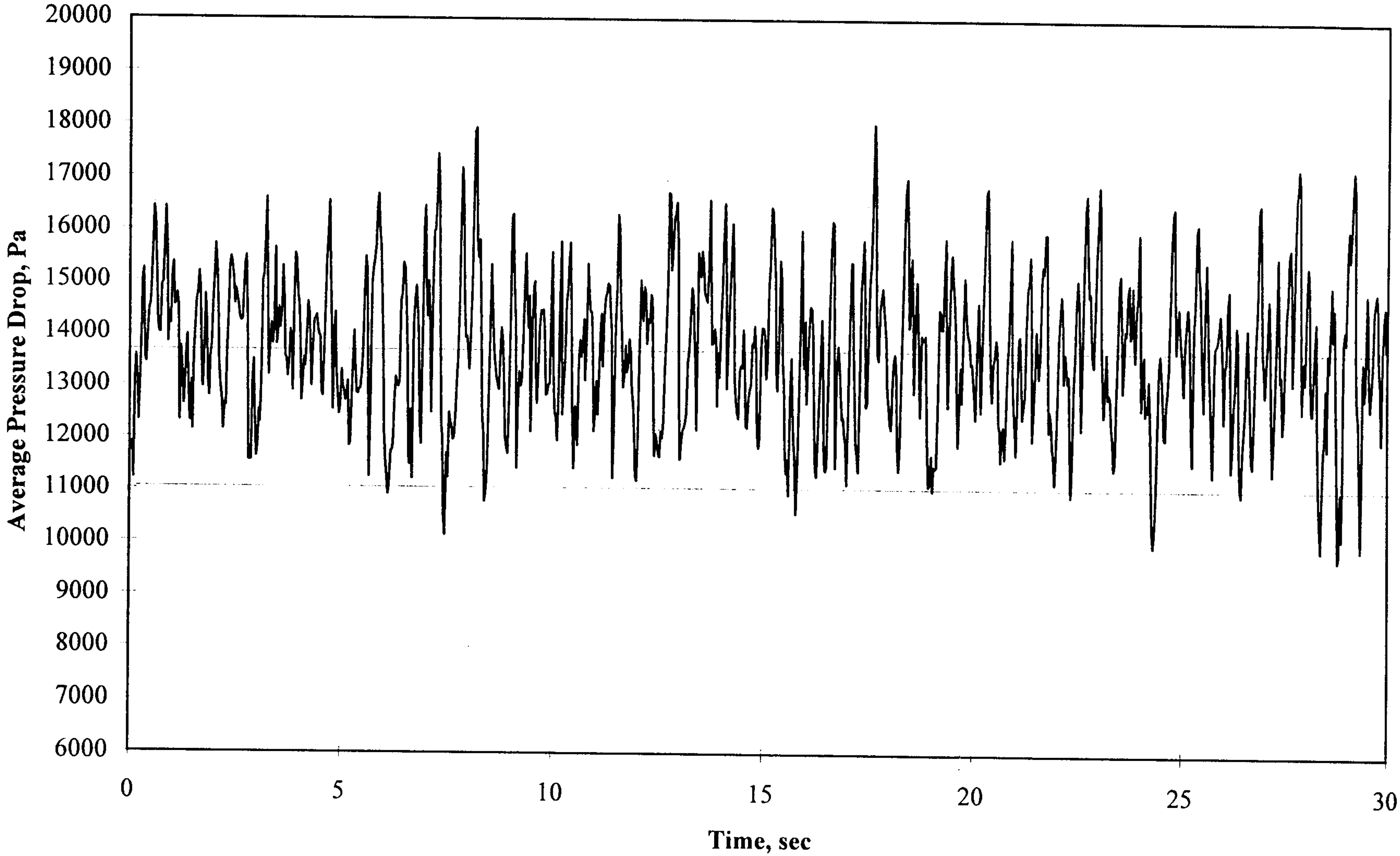


Figure 11. 100% LVT, 0 ppm, Vsl = 1.5 m/s, Vsg = 10 m/s

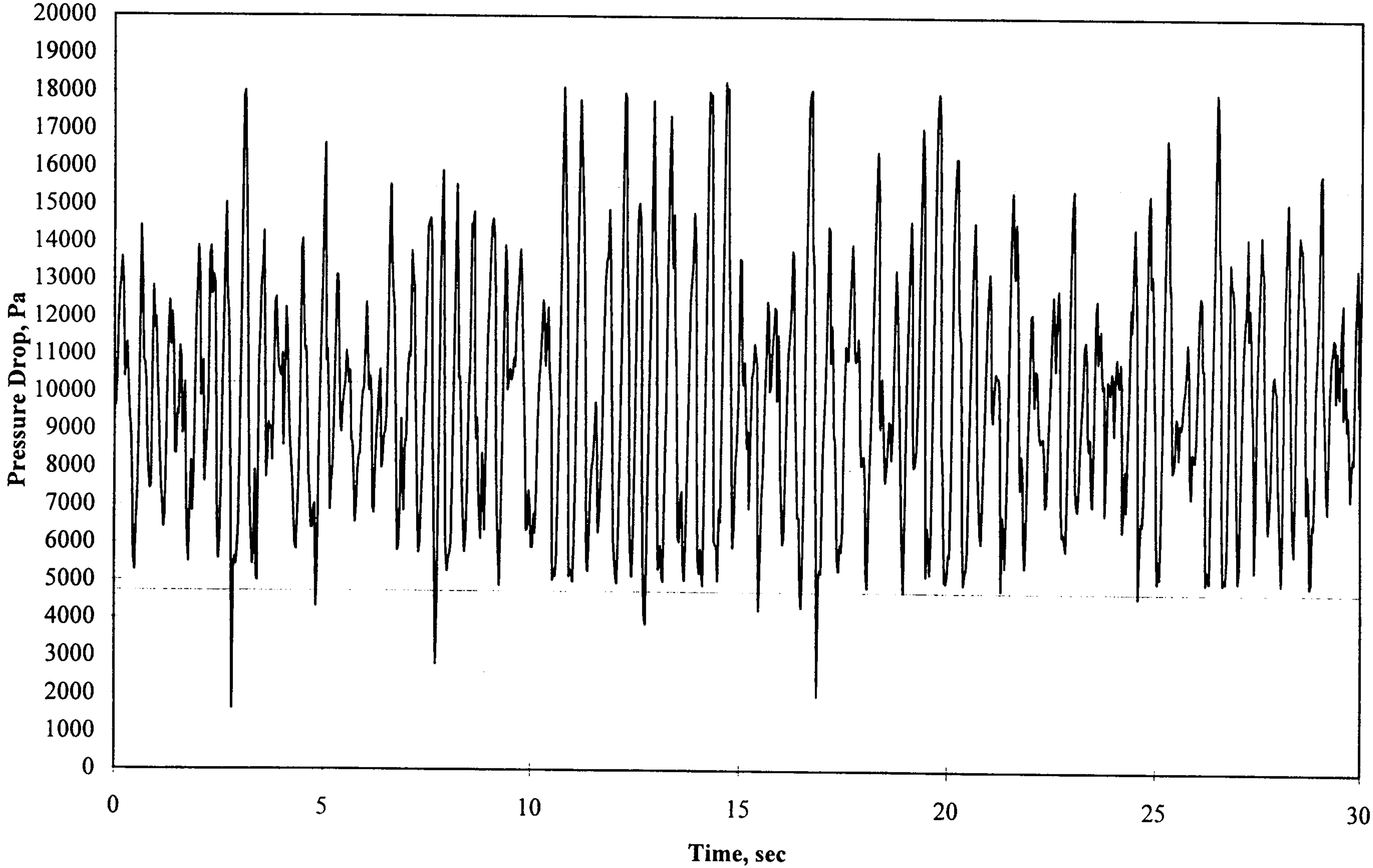


Figure12. 100% LVT 10 ppm, Vsl =1.5 m/s, Vsg = 10 m/s

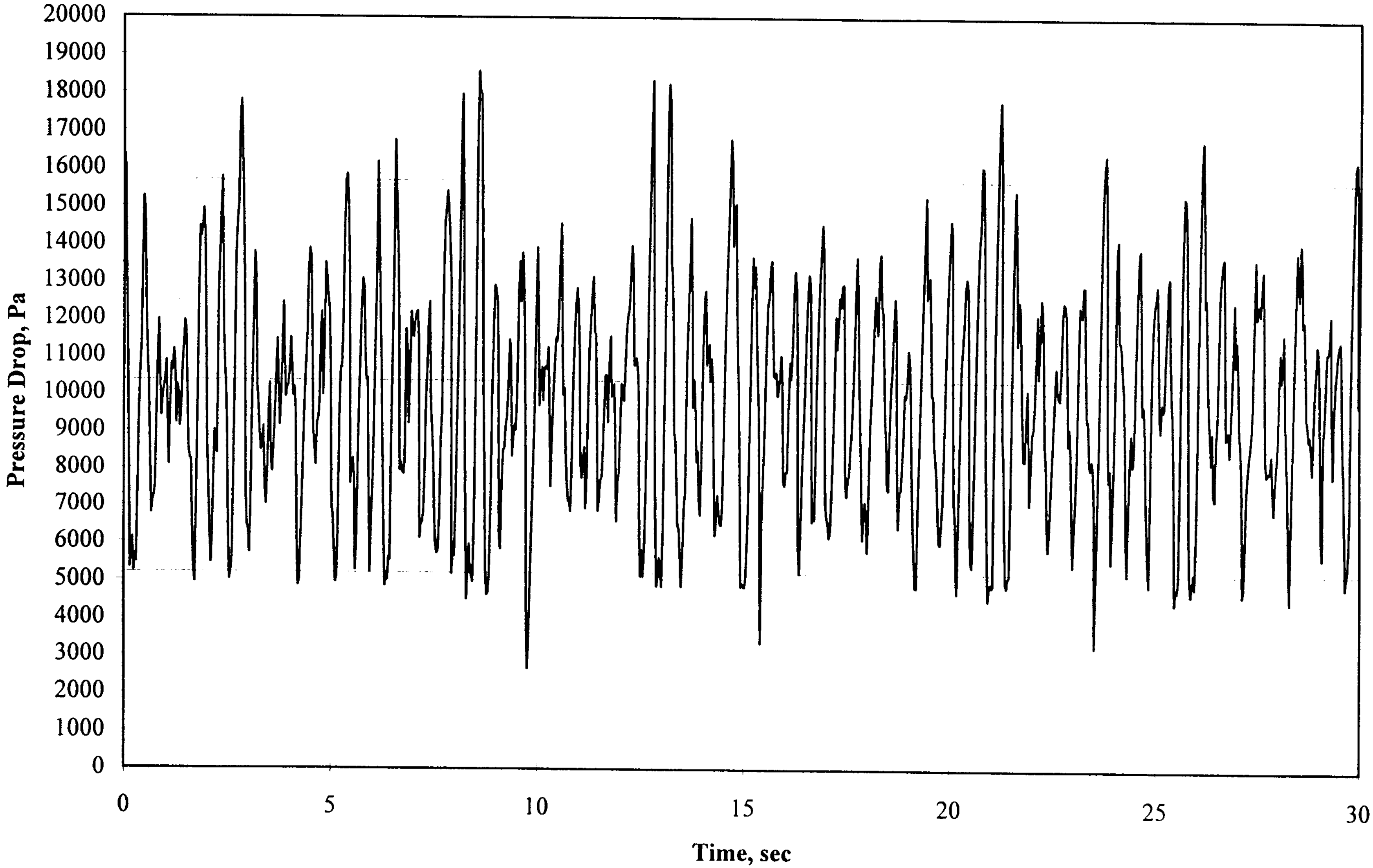


Figure 13. 100% LVT, 50 ppm, Vsl = 1.5 m/s, Vsg = 10 m/s

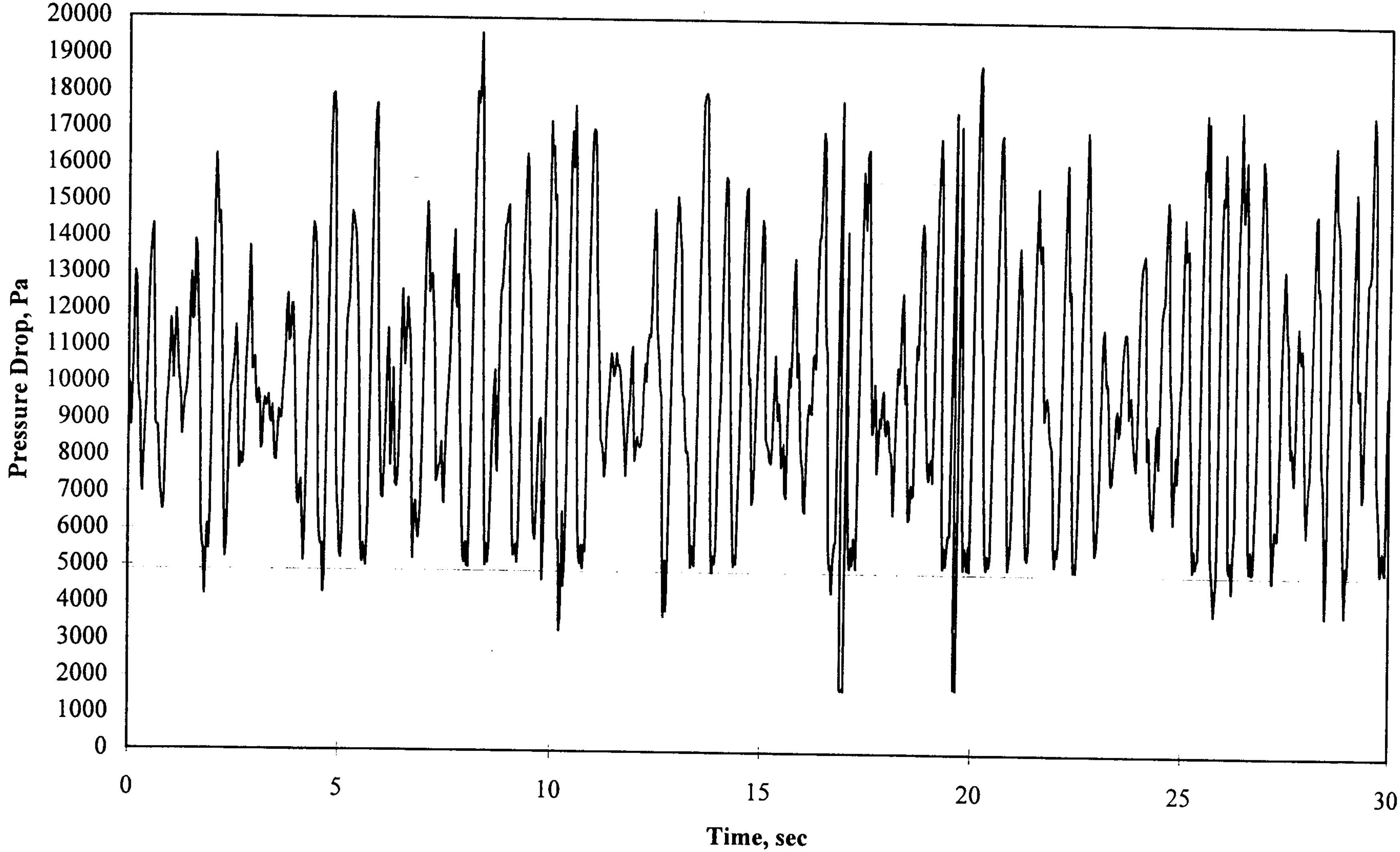


Figure 14. 100% LVT, 0 ppm, Vsl = 2 m/s, Vsg = 1 m/s

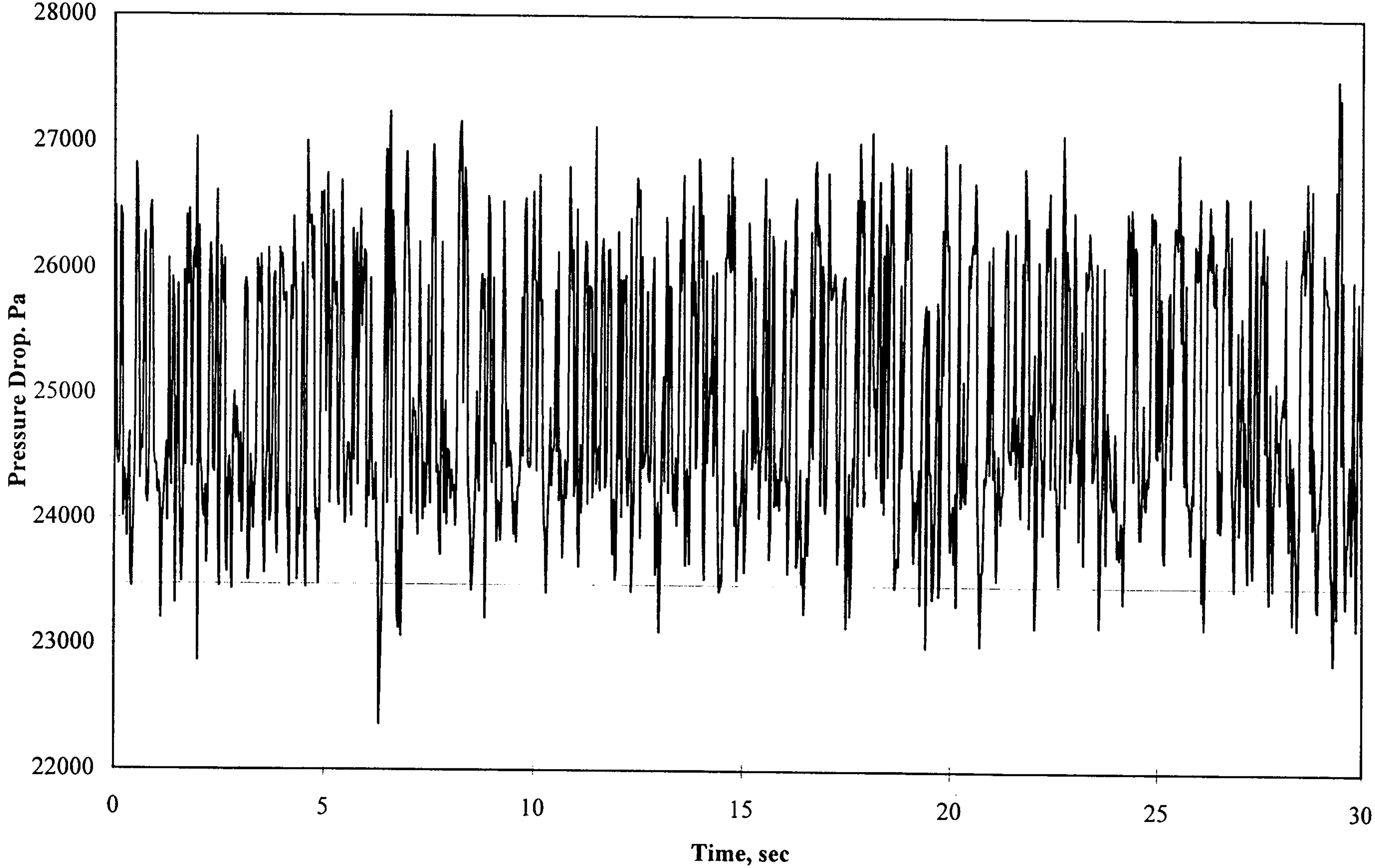
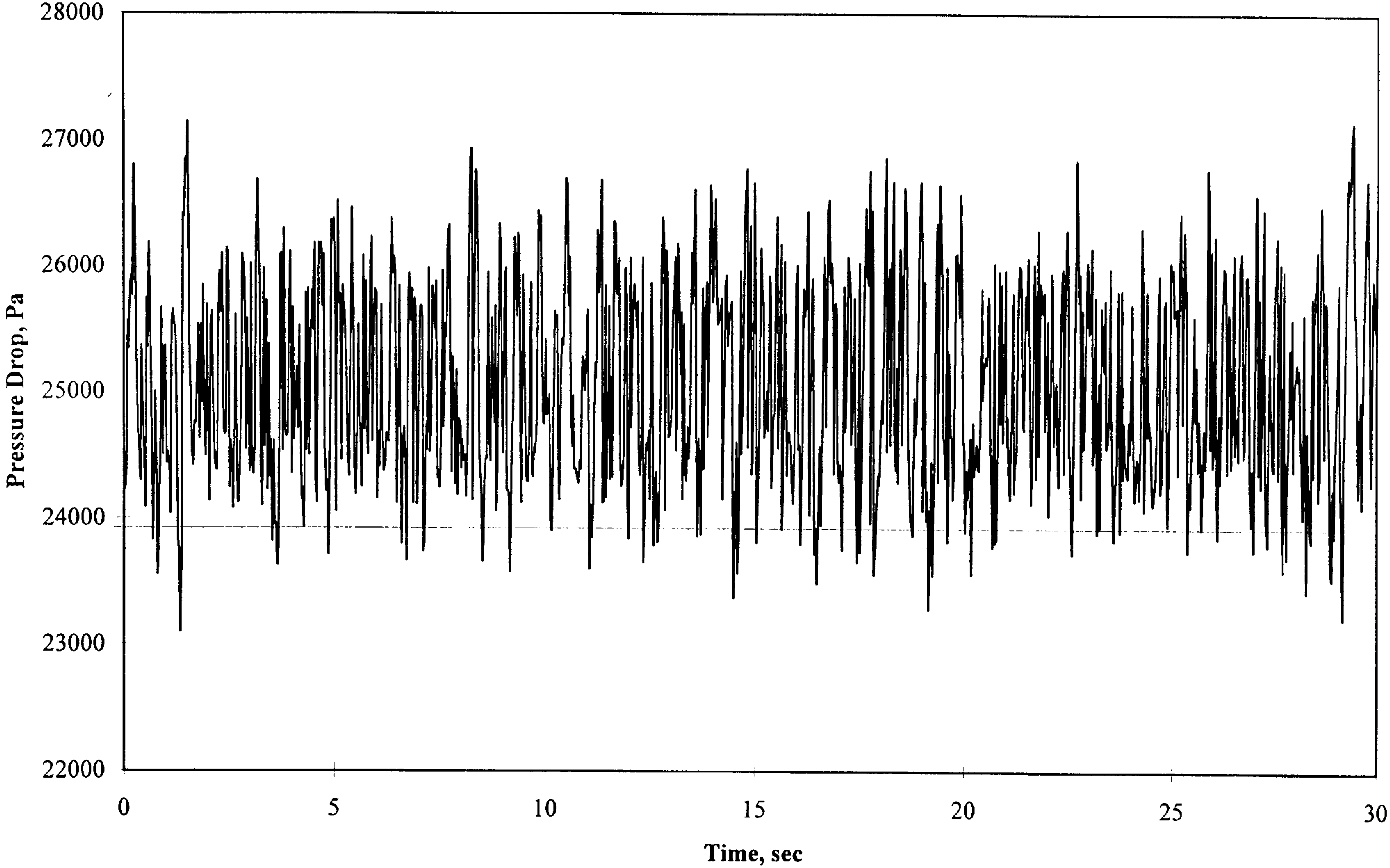


Figure 15. 100% LVT, 10 ppm, Vsl = 2 m/s, Vsg = 1 m/s



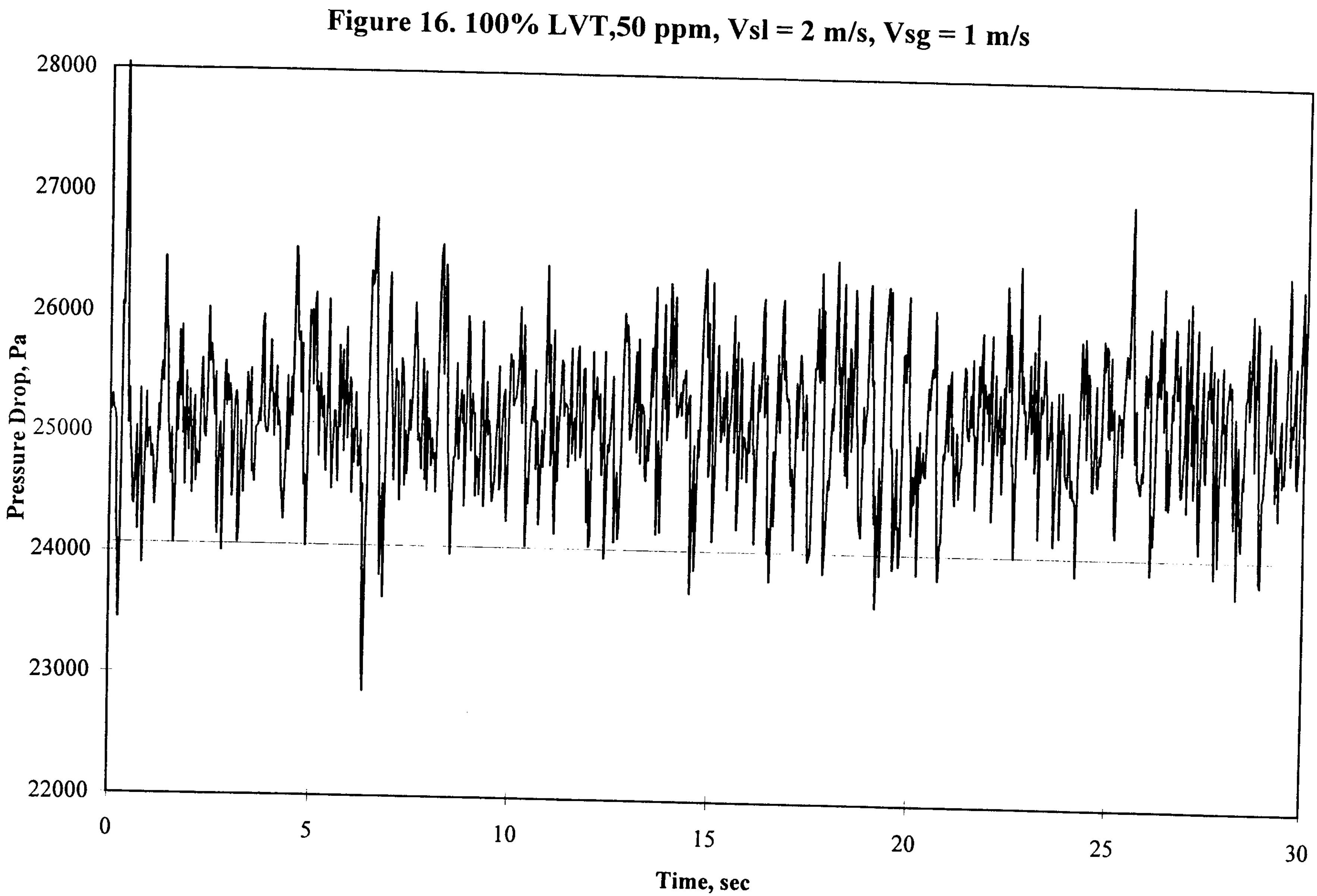


Figure 16. 100% LVT,50 ppm, Vsl = 2 m/s, Vsg = 1 m/s
28000
27000
26000
25000
24000
23000
22000
Pressure Drop, Pa
0
5
10
15
20
25
30
Time, sec

Figure 17. 50% LVT, 0 ppm, Vsl = 0.4 m/s, Vsg = 4 m/s

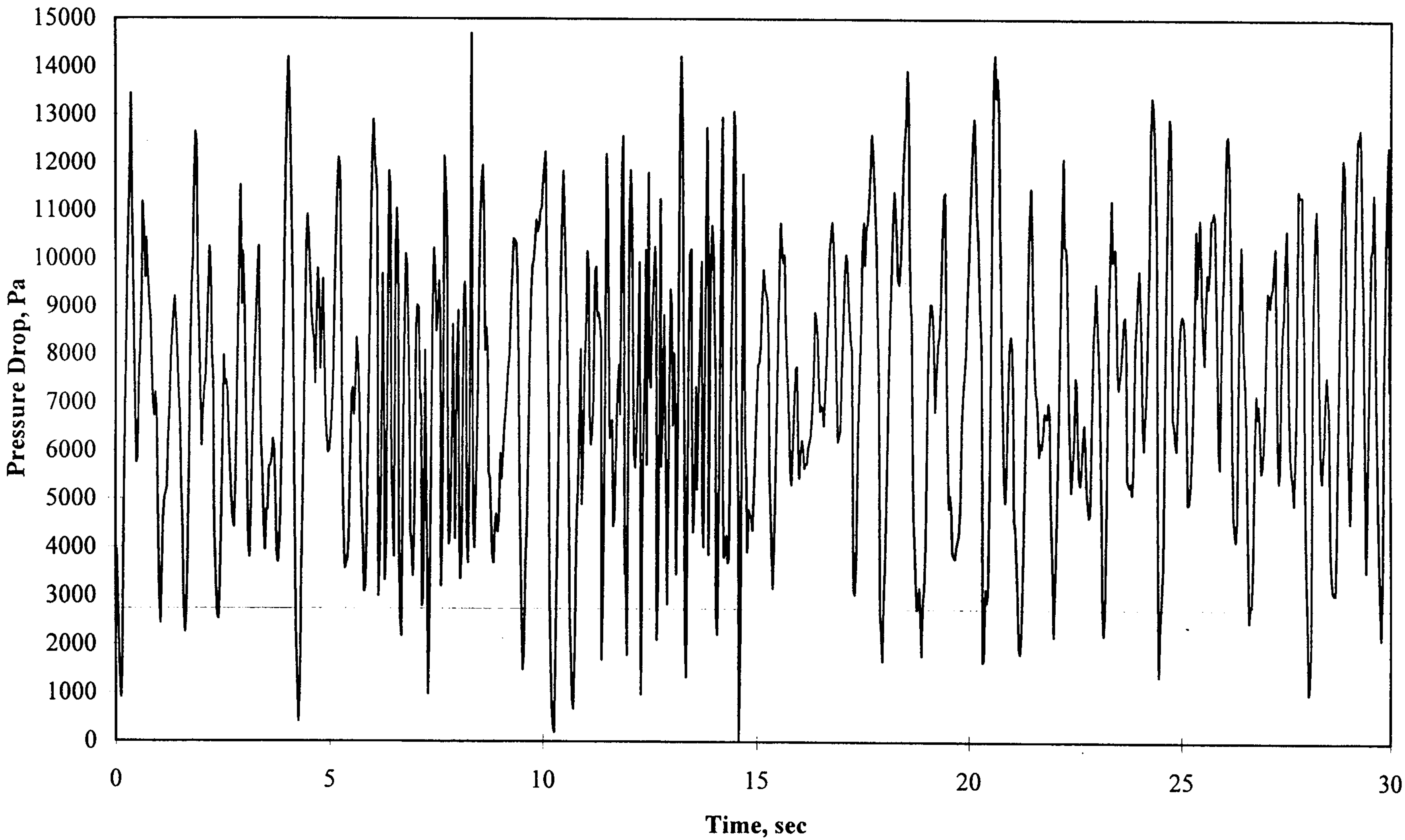


Figure 18. 50% LVT, 10 ppm ,Vsl = 0.4 m/s, Vsg = 4 m/s

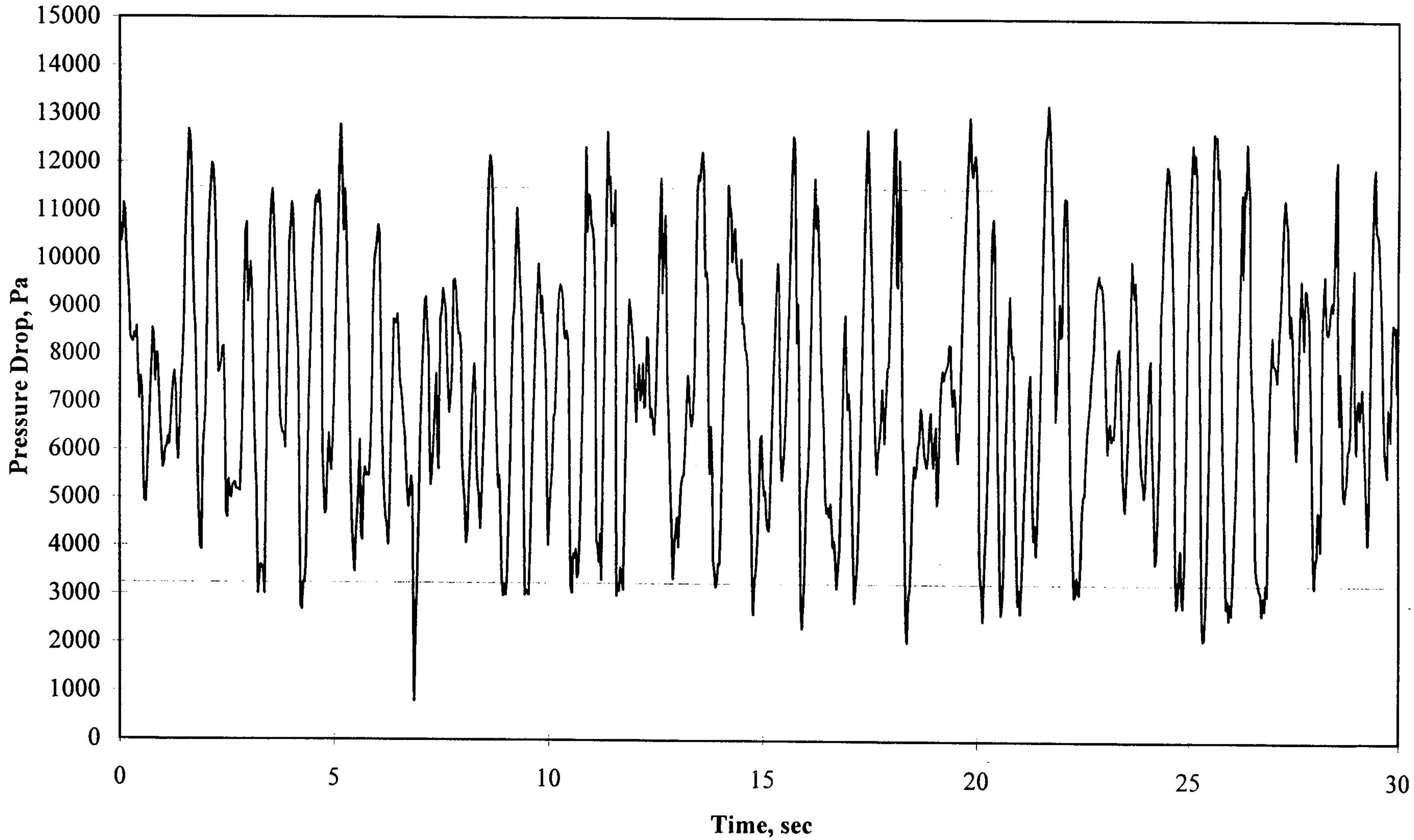


Figure 19. 50% LVT, 50 ppm, Vsl = 0.4 m/s, Vsg = 4 m/s

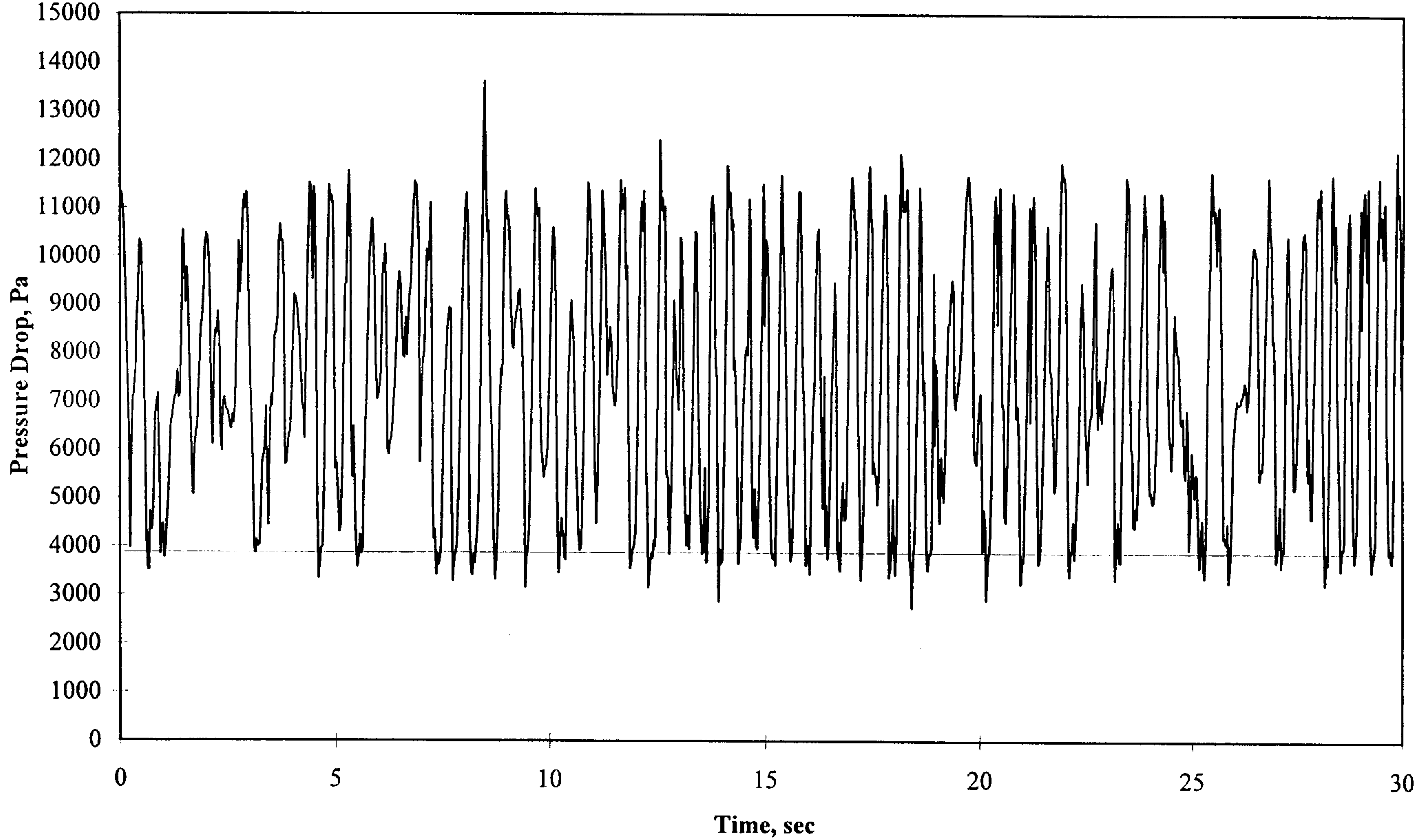


Figure 20. 50% LVT, 0 ppm, Vsl = 1 m/s, Vsg = 4 m/s

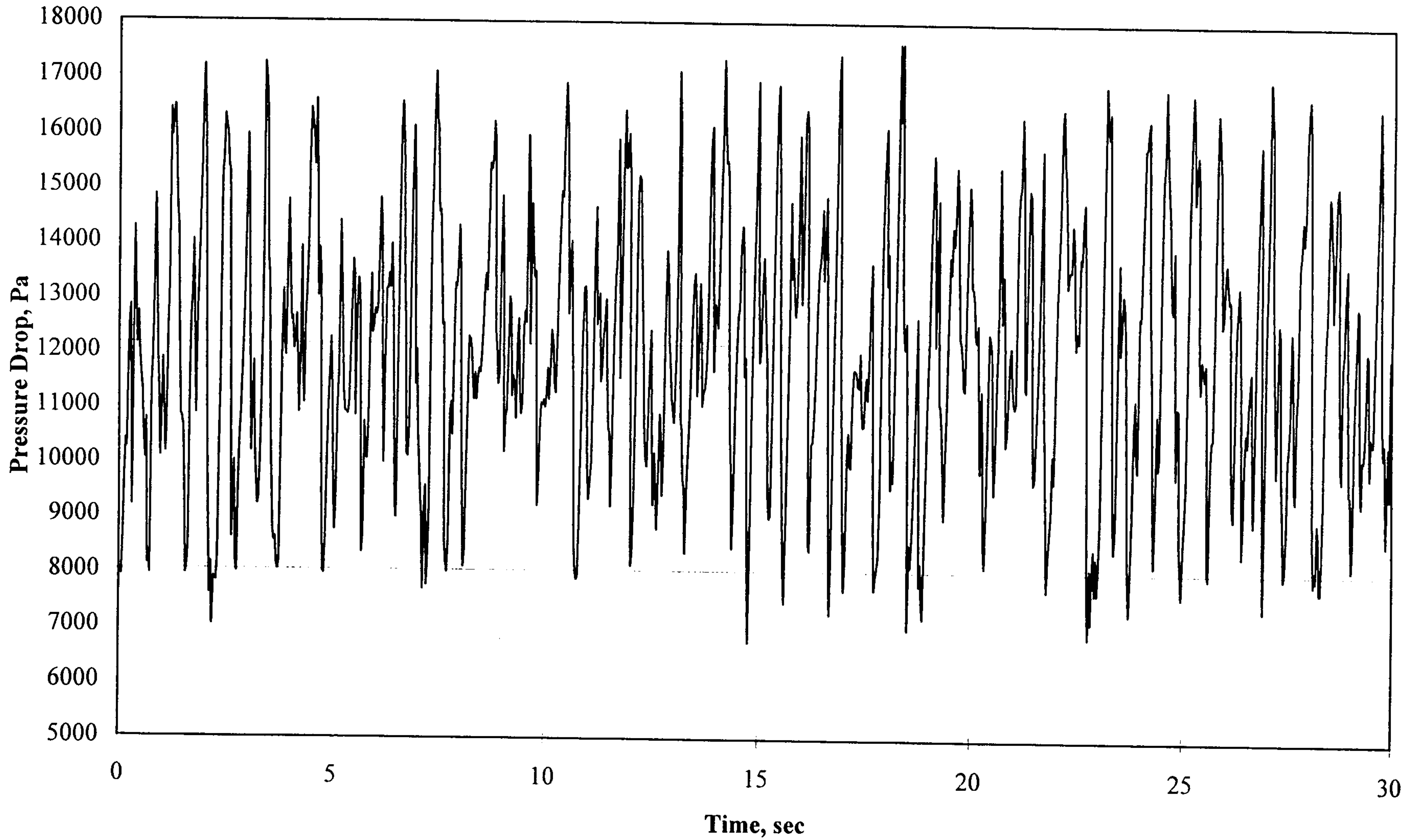


Figure 21. 50% LVT, 10 ppm, Vsl = 1 m/s, Vsg = 4 m/s

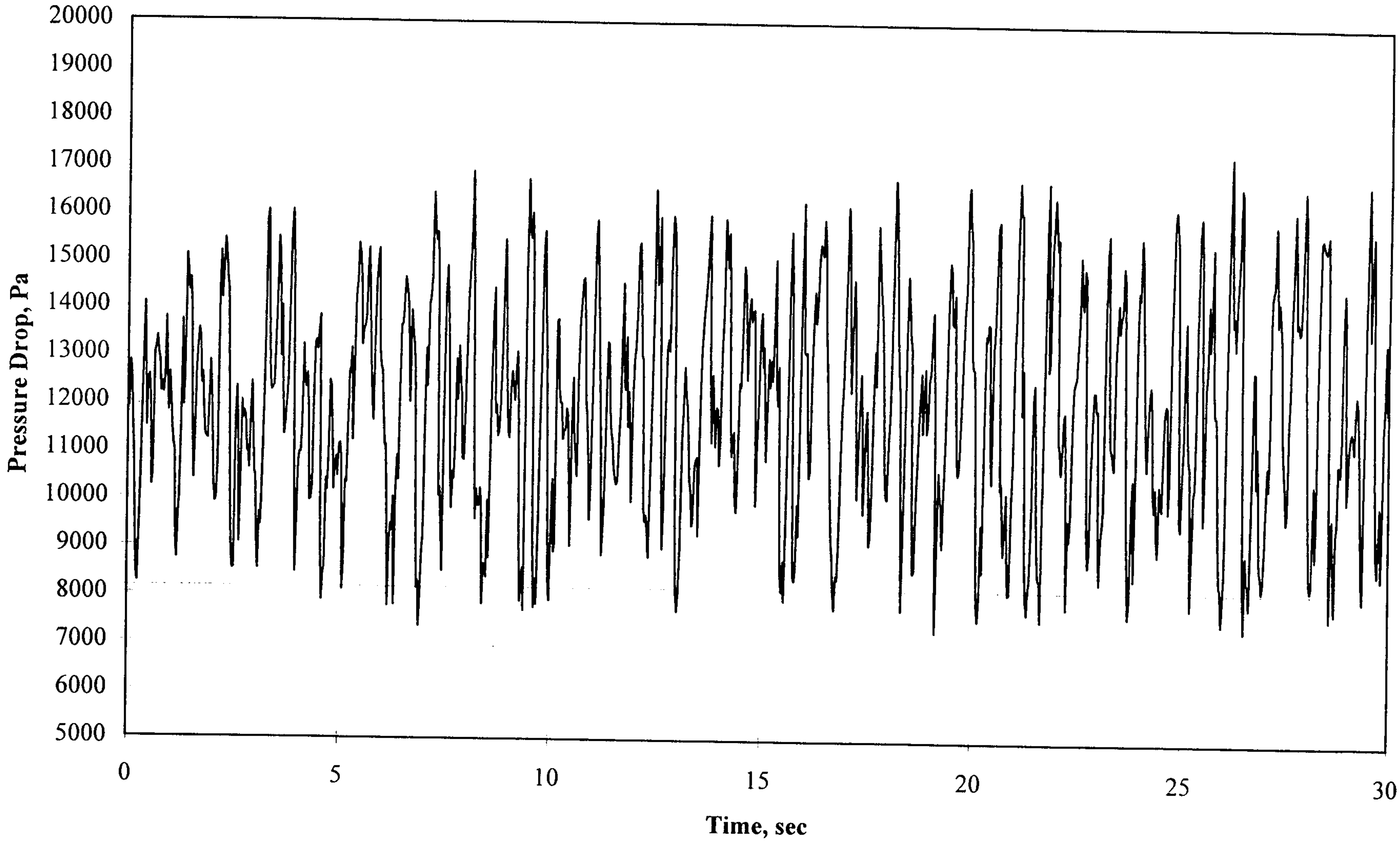


Figure 22. 50% LVT, 50 ppm, Vsl = 1 m/s, Vsg = 4 m/s

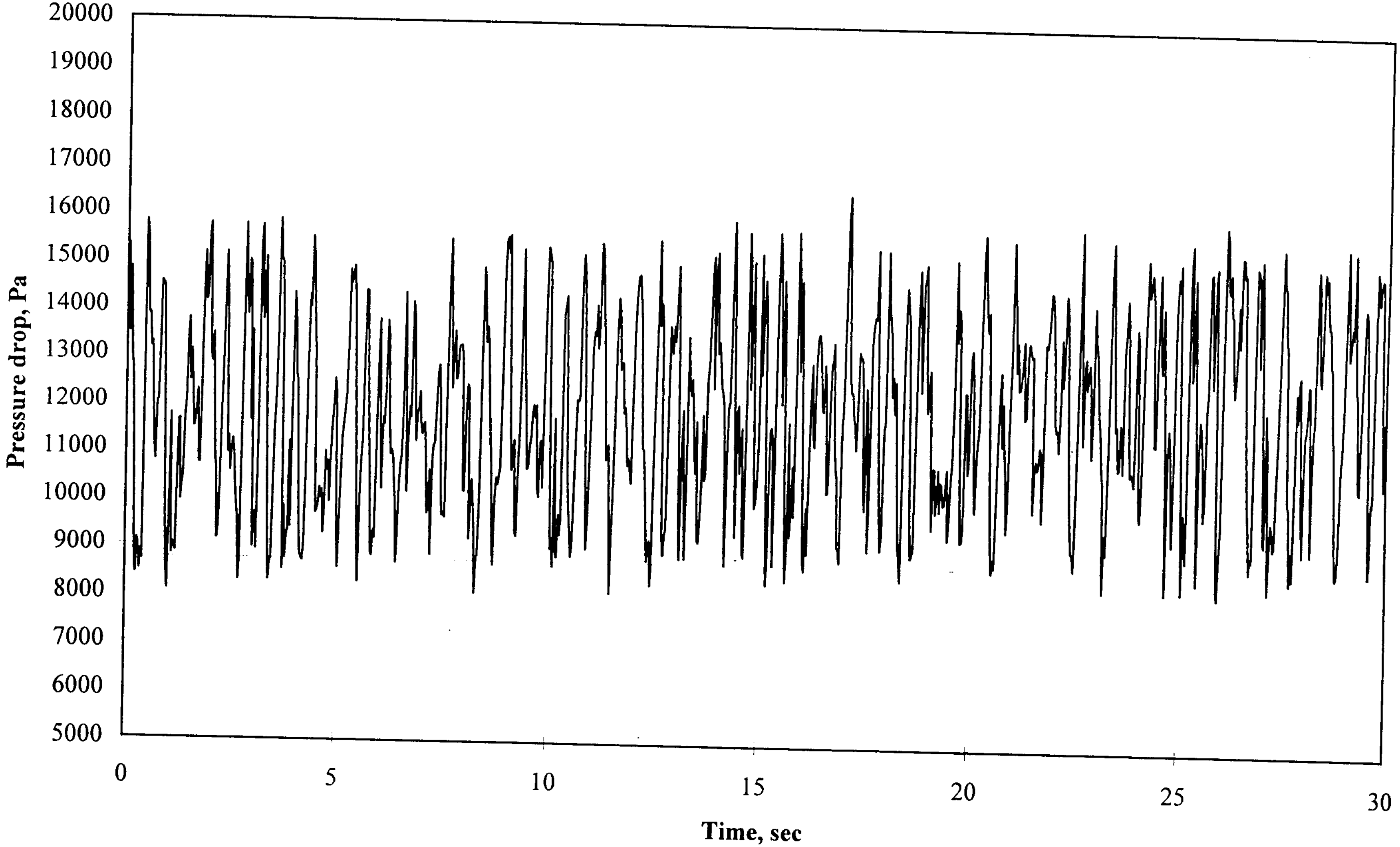


Figure 23. 50% LVT, 0 ppm, Vsl = 1.5 m/s, Vsg = 4 m/s

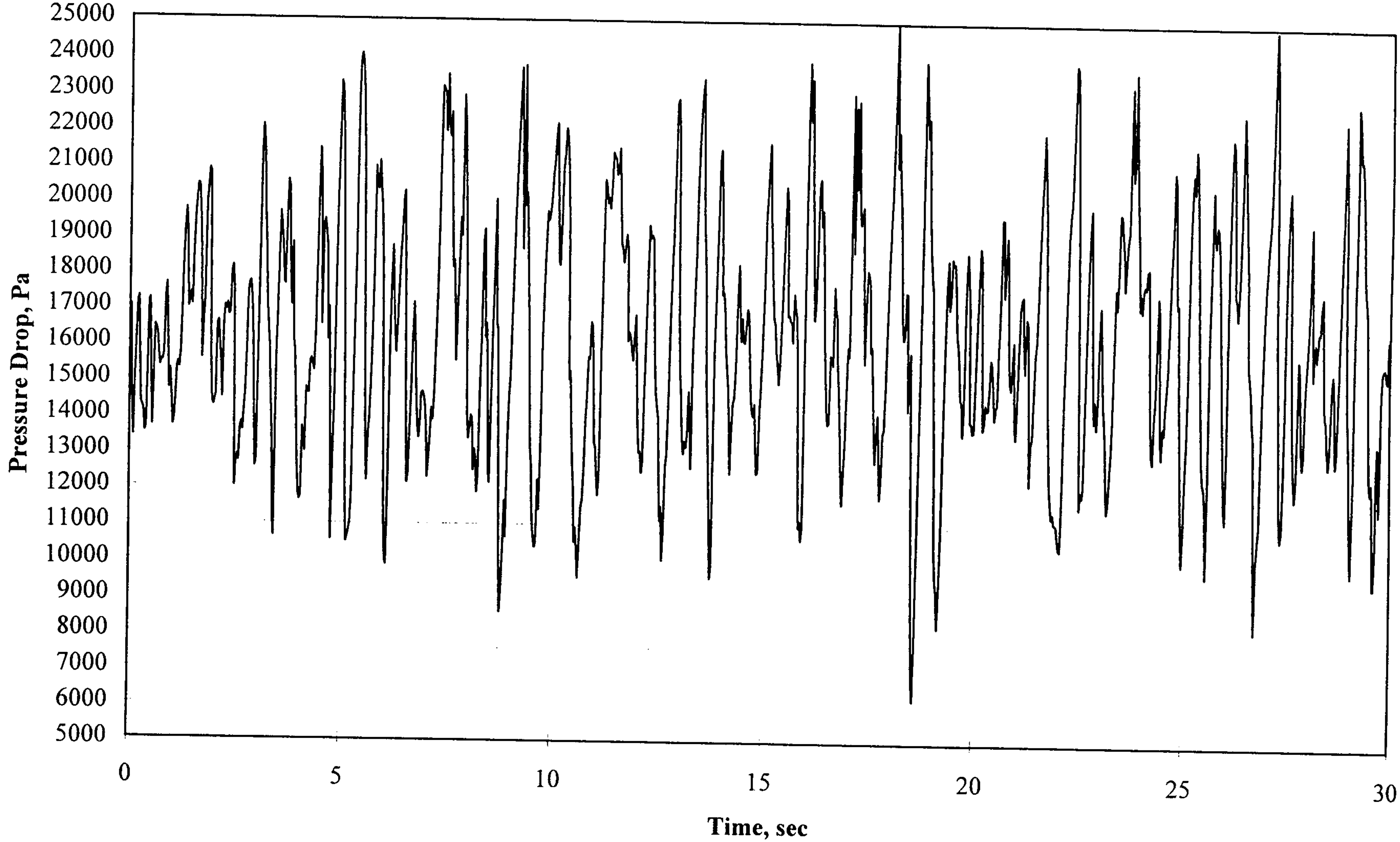


Figure 24. 50% LVT, 10 ppm, Vsl = 1.5 m/s, Vsg = 4 m/s

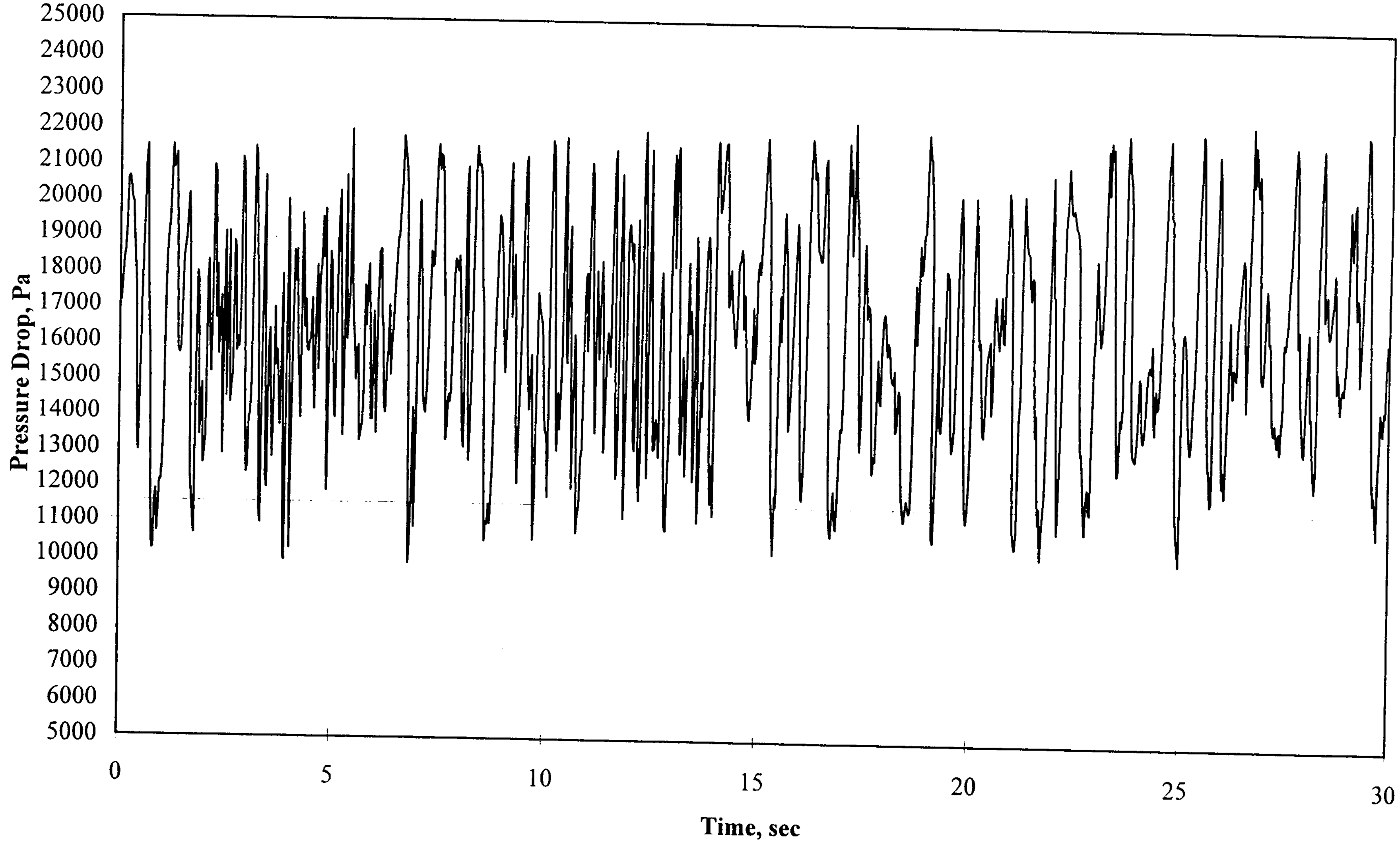


Figure 25. 50% LVT, 50 ppm, Vsl = 1.5 m/s, Vsg = 4 m/s

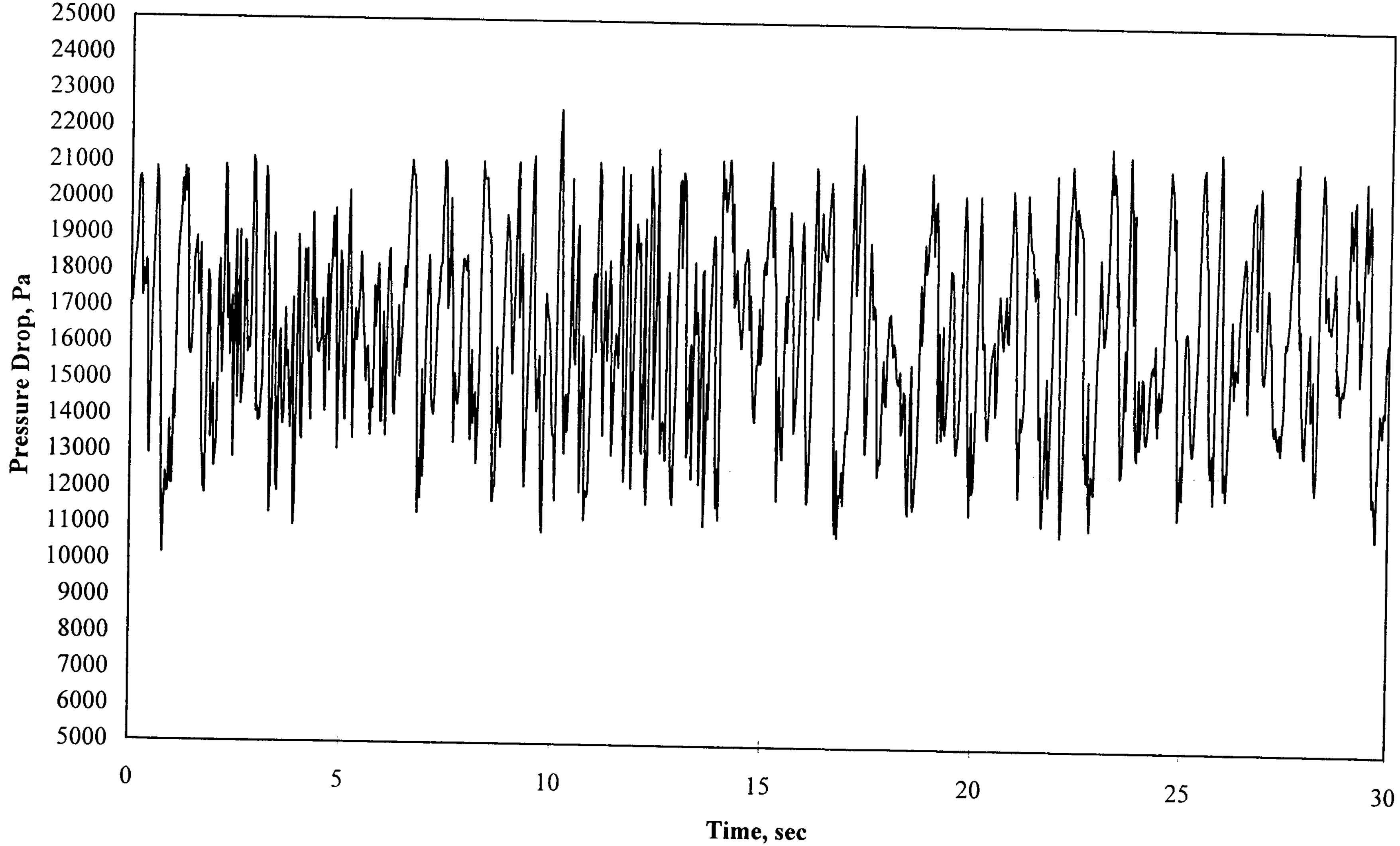


Figure 26. 50% LVT, 0 ppm, Vsl = 1.5 m/s, Vsg = 10 m/s

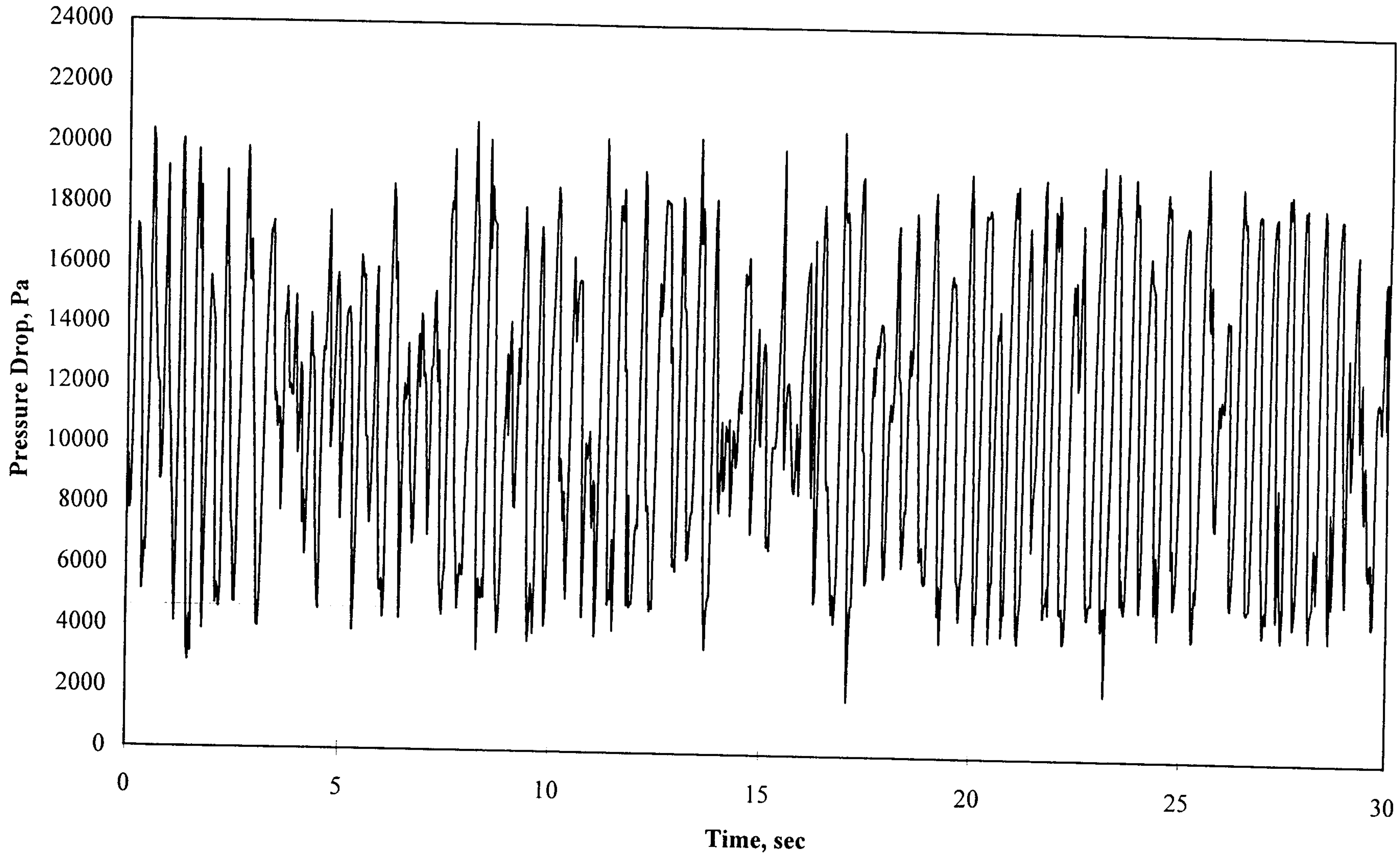


Figure 27. 50% LVT, 10 ppm, Vsl = 1.5 m/s, Vsg = 10 m/s

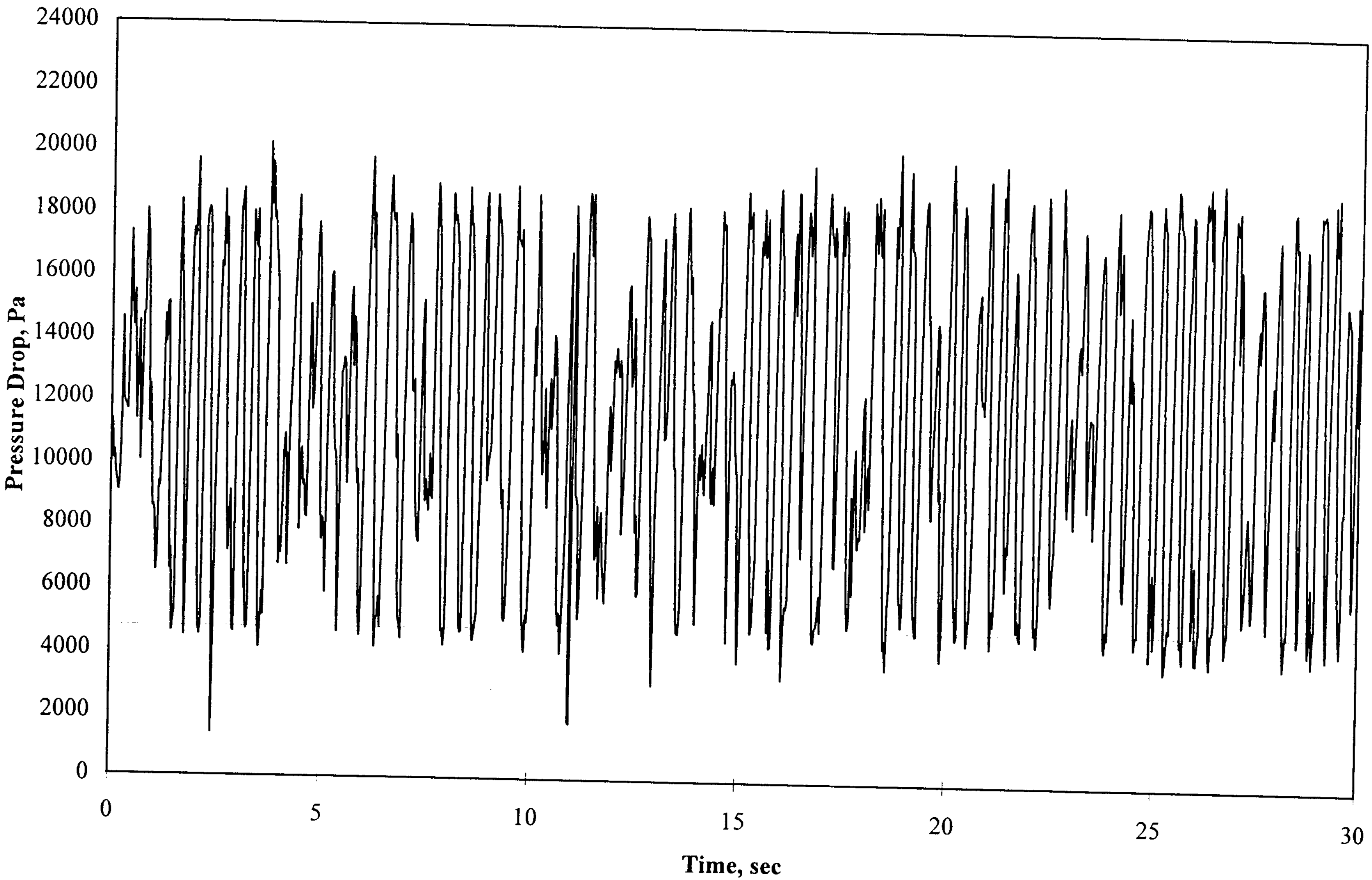


Figure 28. 50% LVT, 50 ppm, Vsl = 1.5 m/s, Vsg = 10 m/s

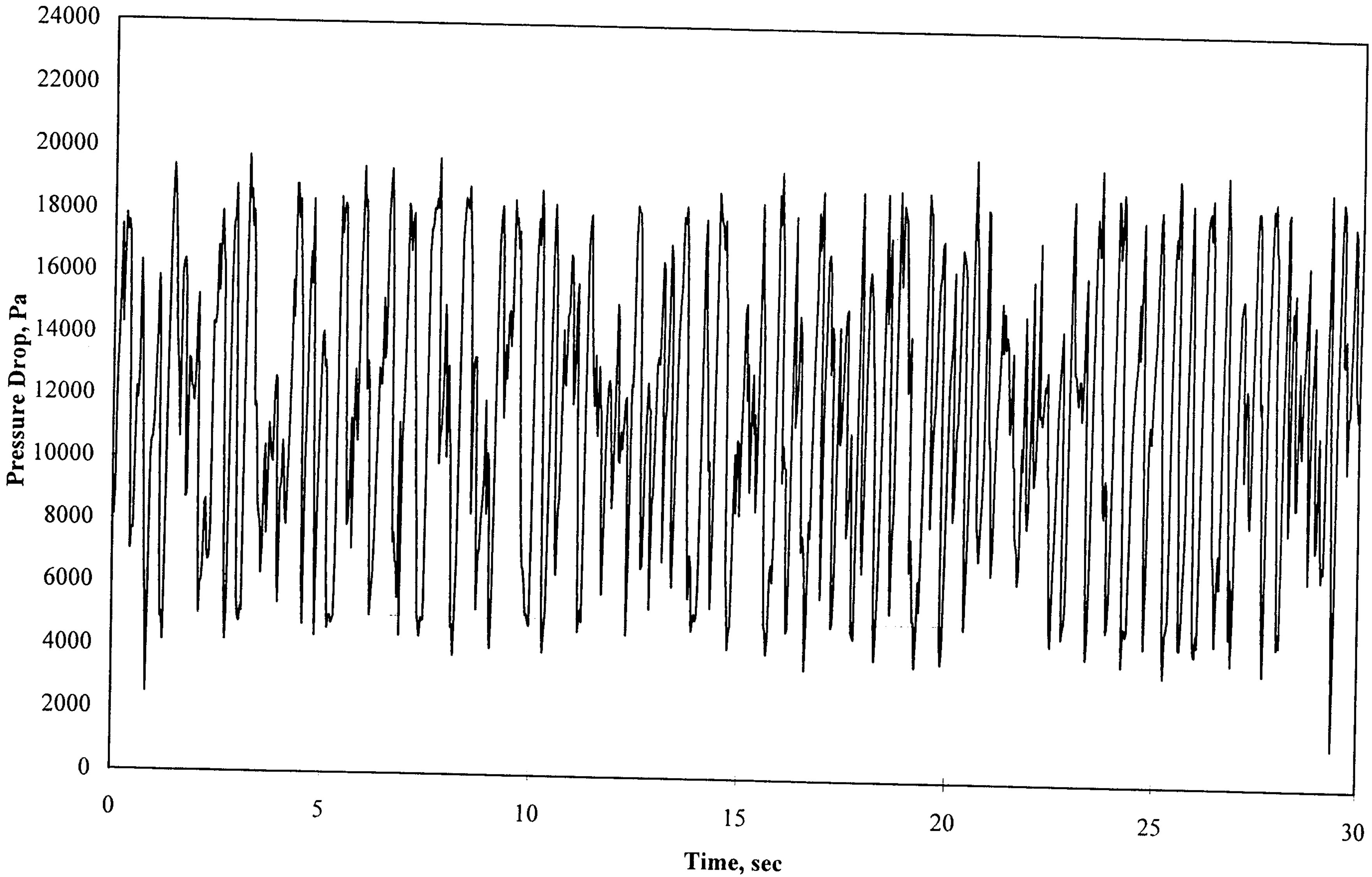


Figure 30. dP, Fluctuation vs. Vsg
Vsl = 1.0 m/s, 90 Degree, 100% Oil

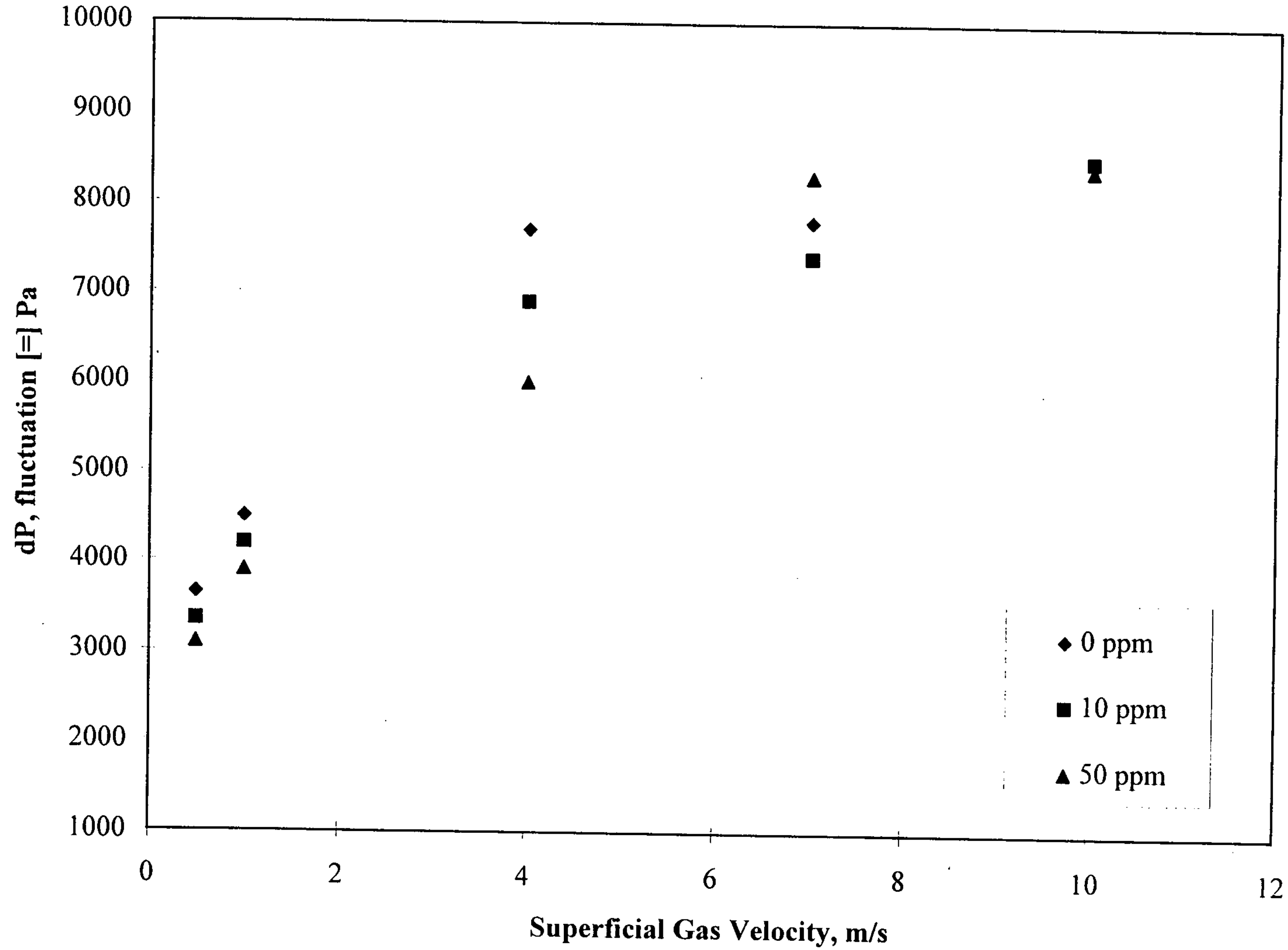


Figure 29. dP, Fluctuation vs. Vsg
Vsl = 0.4 m/s, 90 Degree, 100% Oil

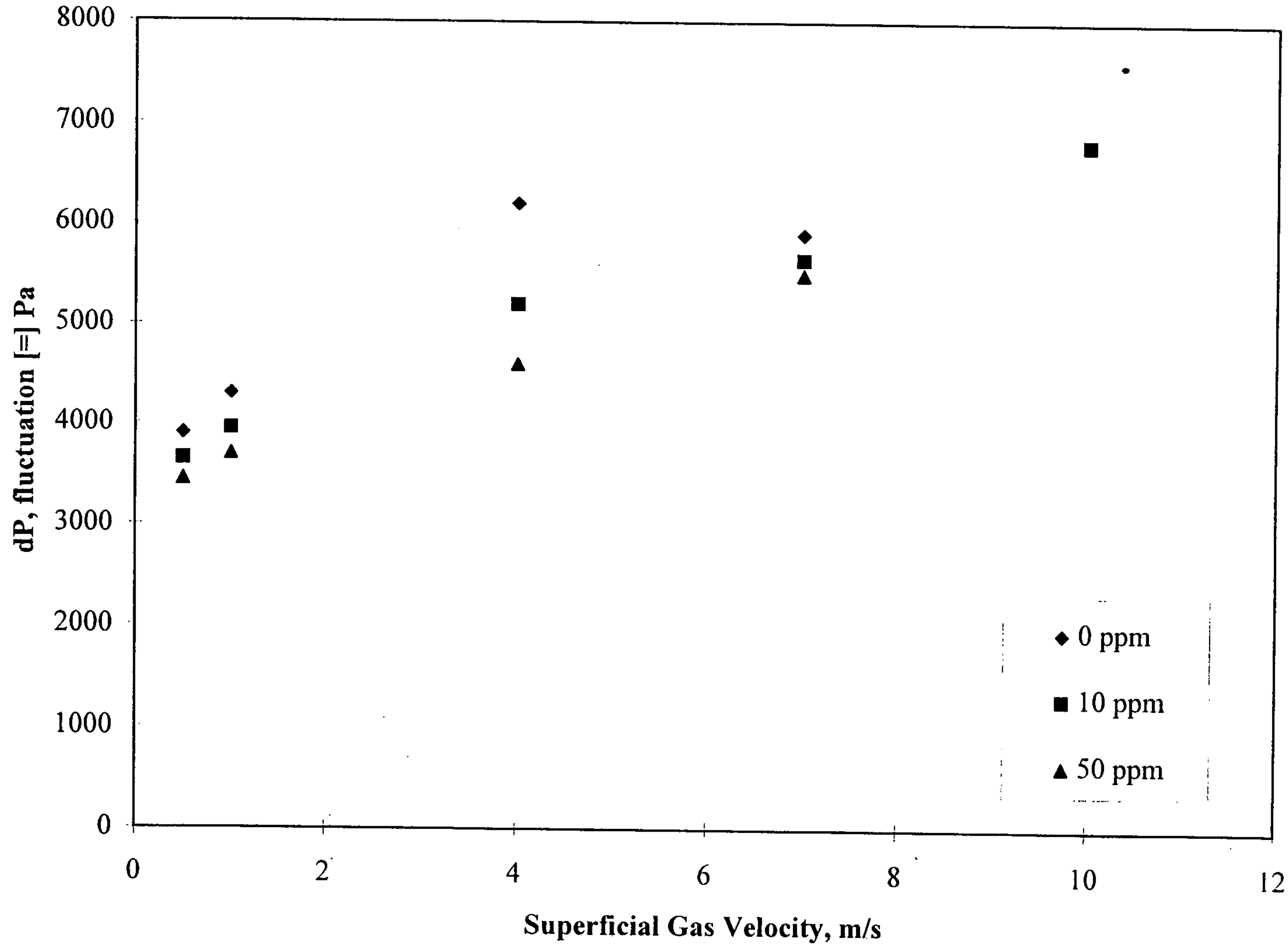


Figure 31. dP, Fluctuation vs. Vsg
Vsl = 1.5 m/s, 90 Degree, 100% Oil

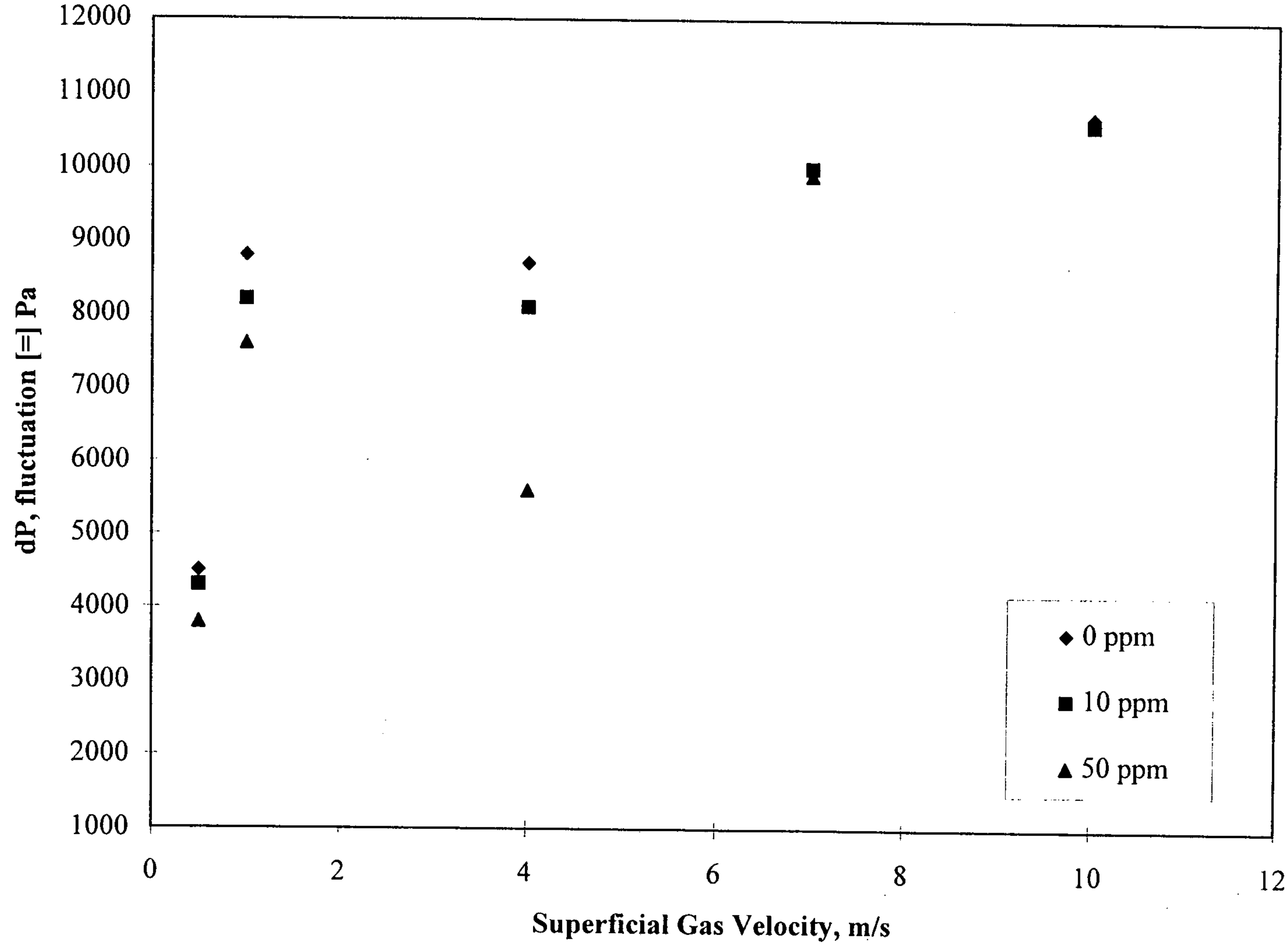


Figure 32. dP, Fluctuation vs. Vsg
Vsl = 2.0 m/s, 90 Degree, 100% Oil

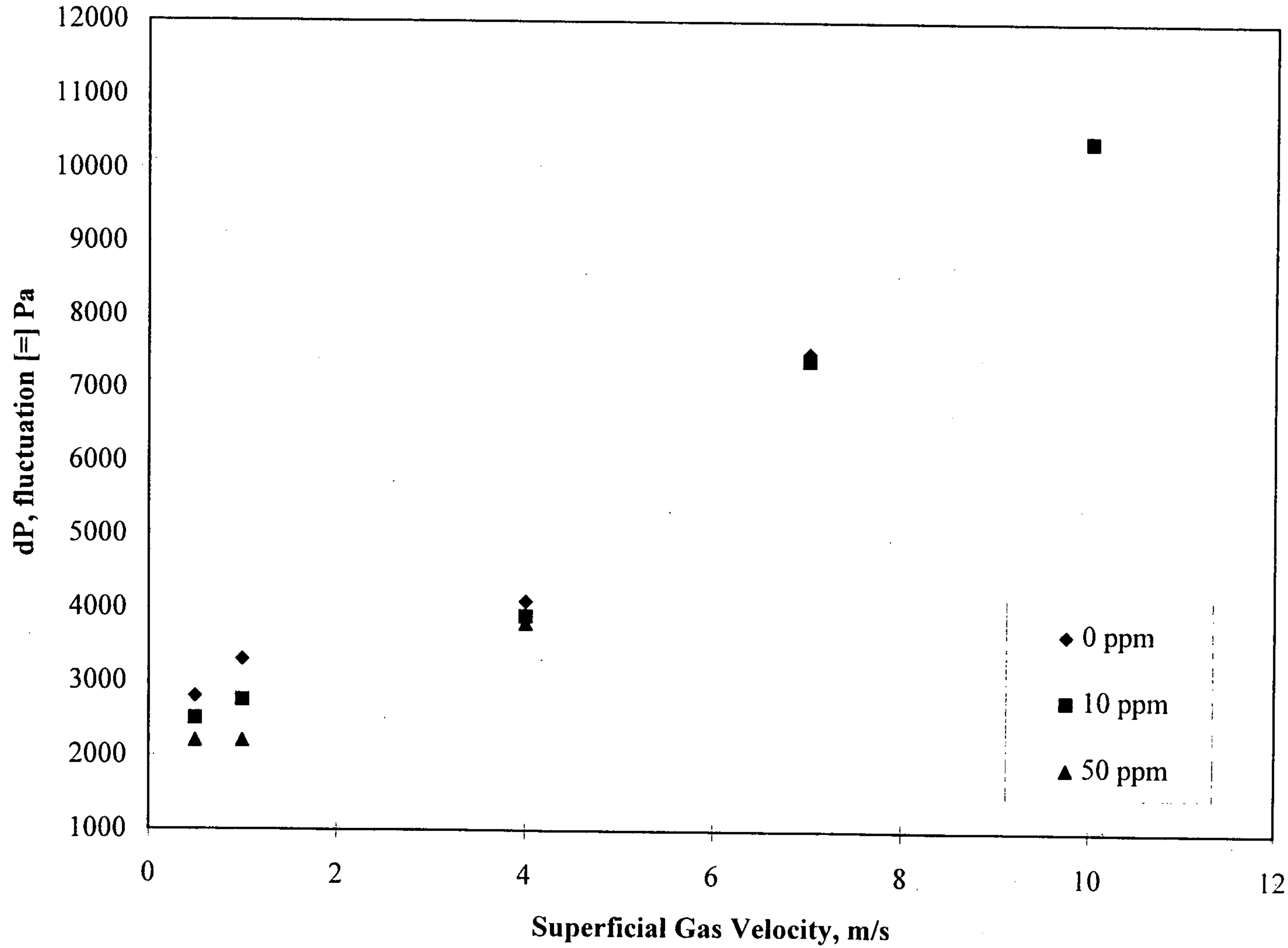


Figure 33. dP, Fluctuation vs. Vsg
Vsl = 0.4 m/s, 90 Degree, 50% Oil

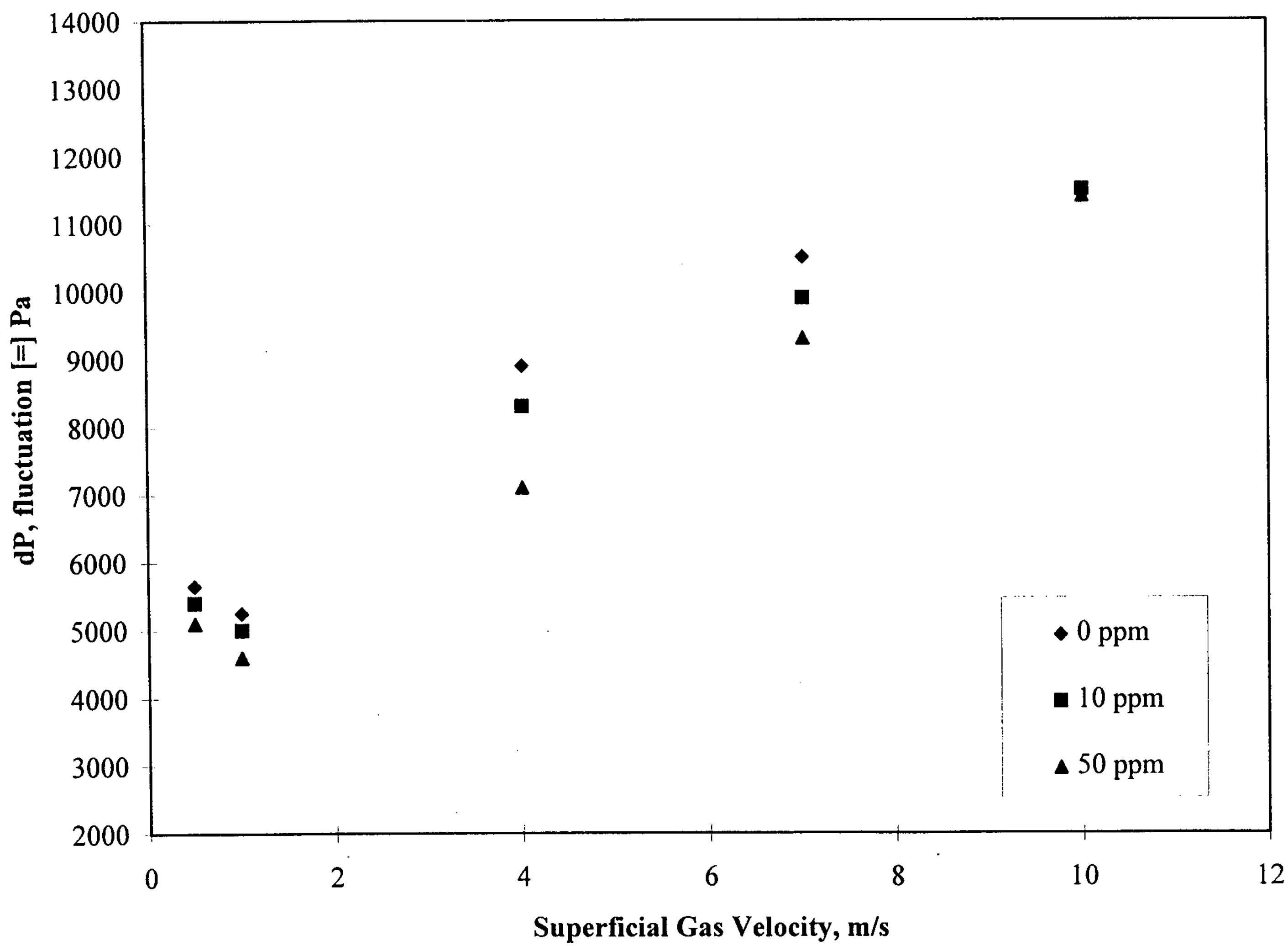


Figure 34. dP, Fluctuation vs. Vsg
Vsl = 1.0 m/s, 90 Degree, 50% Oil

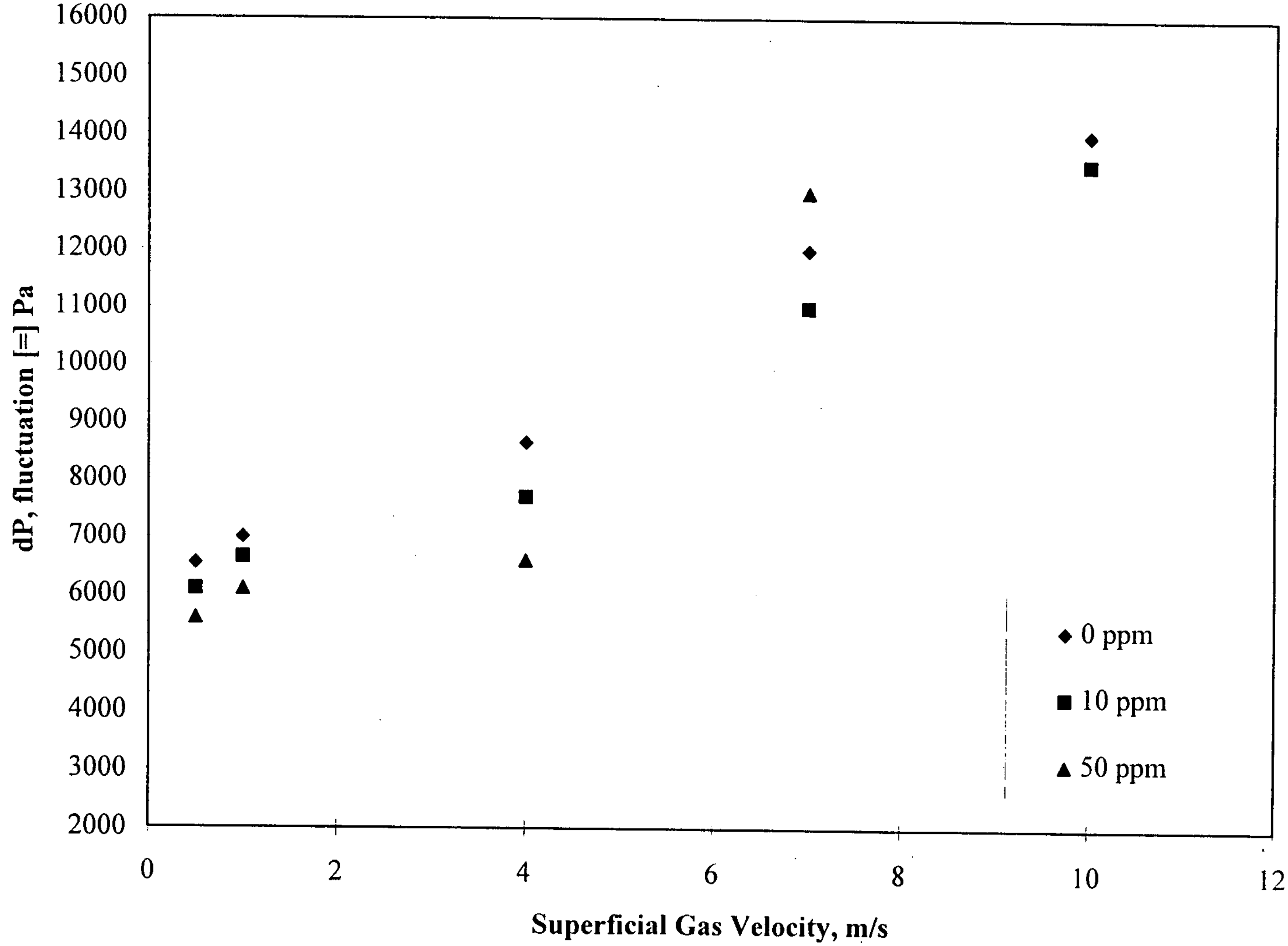


Figure 35. dP, Fluctuation vs. Vsg
Vsl = 1.5 m/s, 90 Degree, 50% Oil

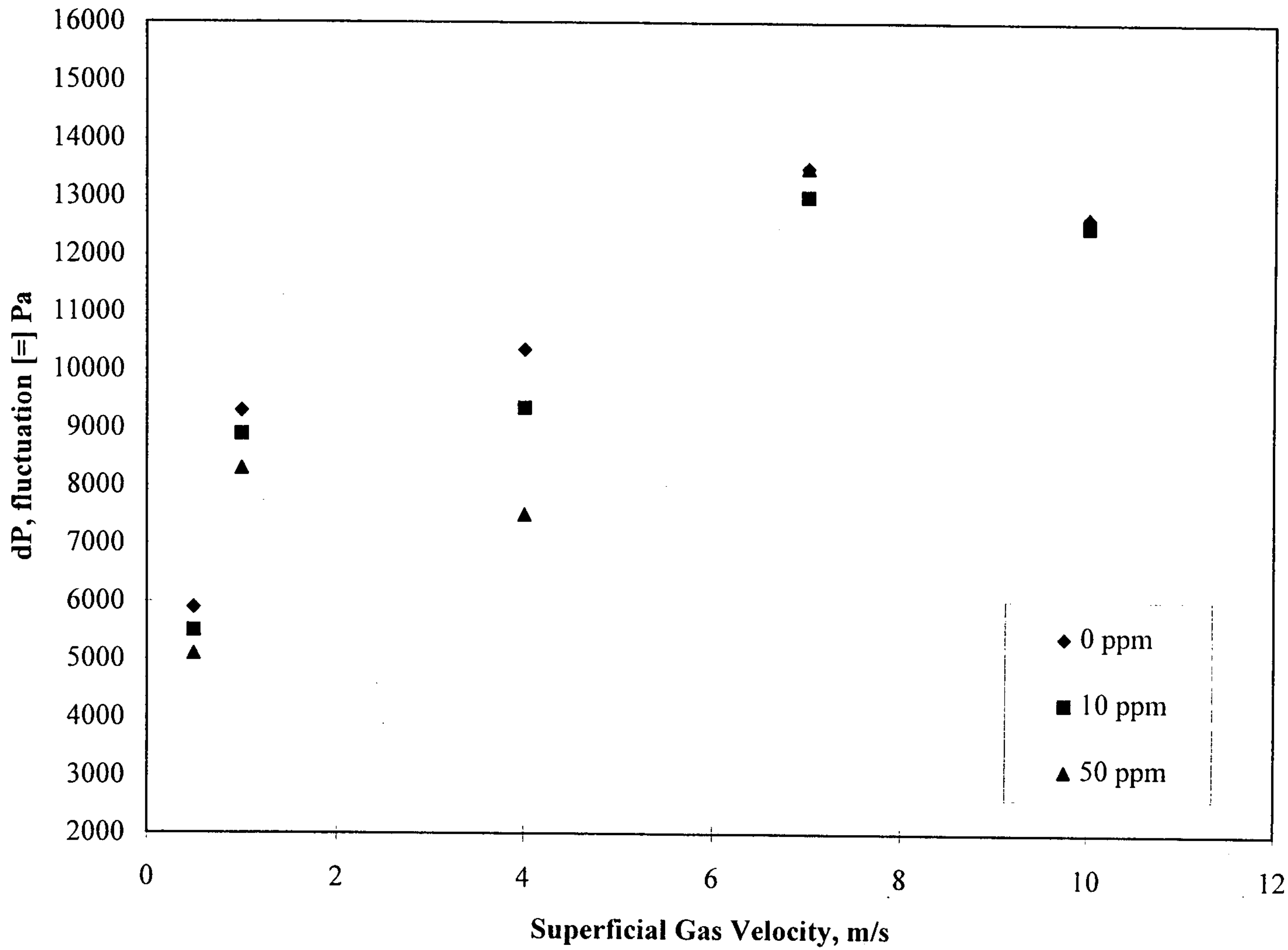


Figure 36. dP, Fluctuation vs. Vsg
Vsl = 2.0 m/s, 90 Degree, 50% Oil