4. HOW IT ALL WORKS – PUTTING THEORY TO PRACTICE

The intricacies of the SPARGE™ program's 'inner workings', specifically a technical description of the Physics behind the Compressible Fluid Dynamics FEA equations that underlie the SPARGE™ program

Enlargement of Horizontal Air Sparge Well Screen Cross Section

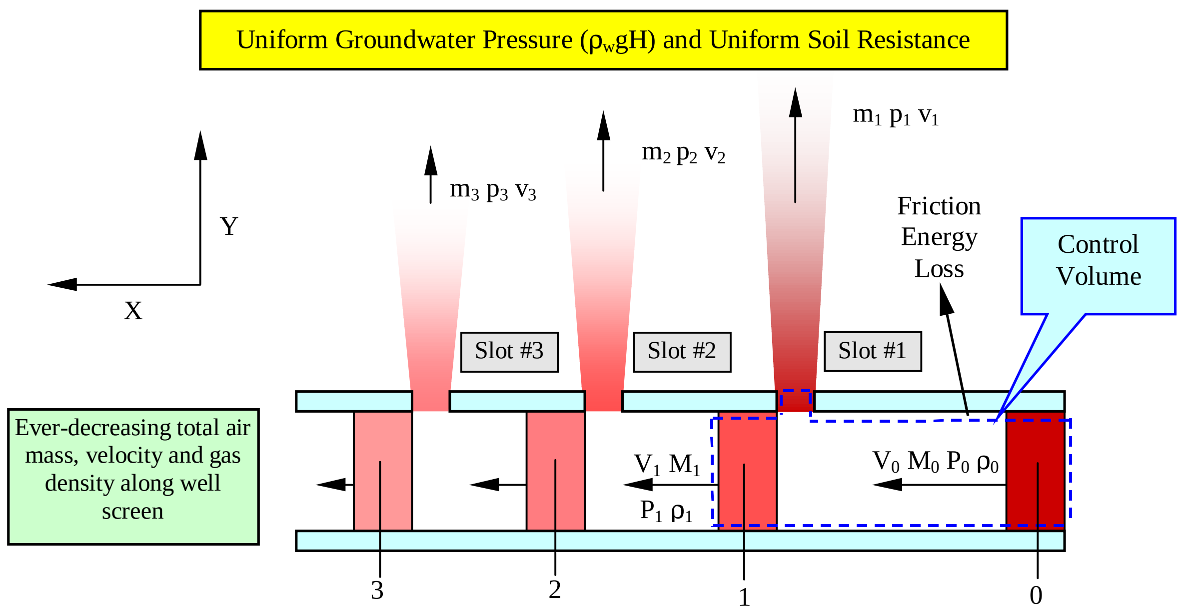


Fig. 3 A Process Flow Diagram of a slotted portion of a horizontal air sparge well. In-well airflow progresses from right to left; air is injected into the formation through each slot. In accordance with the Laws of Physics, due to friction and the loss of mass within the well, in-well pressure *decreases* as one progresses to the left, resulting in ever-decreasing volumes of air being discharged from successive slots. The referenced paper identified in the text supplies far more information on this process, including equations of state.

itself, is described in some detail within a previously published Integrity Engineering (IE) technical paper entitled **The Engineering Theory and Application of Air Sparge and Soil Vapor Extraction -** A *Treatise in Distributed Compressible Fluid Transport using Horizontal Wells* [5]. The rudiments of how the elemental equations of state for compressed gas flowing through a portion of well screen are derived are discussed in some detail in this paper. One fundamental diagram upon which the basic equations are developed is replicated from this paper and is provided herein as Figure 3.

Employing the '…**Engineering Theory and Application**…' paper as a guide, presuming that the reviewer of the current paper has read and 'digested' the referenced equation-laden paper, the question that must be asked (and answered) is "Given the *technical* mathematical requirements and contents of the

[5] Click the 'Technical Papers' tab of the Integrity Engineering, Inc. website (www.IntegrityEngg.com), where this paper may be downloaded in four separate parts, each as an individual Adobe pdf file. The paper is free to all.

SPARGE™ FEA program, *exactly how* does one use it?" Good question! The answer is discussed in the ensuing explanatory text and is illustrated in the following two Figures, 4 and 5.

When SPARGE™ was developed, it was done with the expressed intent that the entirety of its use be done in-house at Integrity Engineering, and not sold or licensed to outside firms for their use. This was a difficult decision, but in the end, the absolute correct one, for it did not require anybody beyond our doors to know and fully understand the 'language', intricacies and nuances of distributed compressible gas flow and their systems. Without *years* of education and *practical* practice in Thermodynamics and Fluid Dynamics (both Compressible and Incompressible), quite honestly, the results of any SPARGE™ analysis to the novice user would appear as a huge file of gibberish. It would all remain entirely puzzling to one not skilled in the art, so much so that even delving into the science and engineering of it all without this specialized education and experience would become a <u>highly</u> frustrating endeavor. I can state these facts with some certainty. For years prior to and during my developing SPARGE™, I taught Mechanical and Nuclear Engineers Thermodynamics and Fluid Dynamics at the graduate and post-graduate levels. Even with degrees in Engineering that *required* each student to take and successfully pass several courses in these subjects, nearly all found them to be <u>immensely</u> difficult. I used to remark to all before beginning my lectures that Fluid Dynamics and Thermodynamics require a high level of practical intuition and study and even so, what one believes might happen in systems employing these disciplines may just operate *exactly opposite* of that which one thinks. And, this is true, for I had gone through the same frustrations numerous times before, having to go over and over calculations time after time to discern why what I *thought* would occur didn't, and what I believed to be <u>not</u> possible just happened to be what the system did, and did well.

So, with all of this experience under my belt, in consideration of how 'experts' in the topics would have difficulties interpreting SPARGE™ results, I concluded that those without the engineering degree, advanced schooling, PE license(s) and years of practice in the art would be at a total loss. For these reasons, SPARGE™ remains in-house permanently, and as time has proven again and again, this decision was the absolute correct one.

Proceeding with the use of SPARGE™ from the Client's point of view has been tailored to be a *very* easy and uneventful exercise that is illustrated in Step #1 of Figure 4. All the Client needs to do is to provide us with two documents. The first is a physical plan view map of the subject site upon which above ground obstacles are identified and below ground soil types and contaminant(s) isopleths are overlain. The second document is a completed single-page Integrity Engineering-pre-prepared form [6] to specify what the Client wants the system to 'do', inclusive of any particular 'special needs' or added accoutrements s/he wants in that system. If needed, and this has been done many many times over the years, we will 'walk the Client' through the *Well Design Checklist*© completion process, even to the extent of completing the form for him/her, ensuring afterwards that what we understand s/he wants is properly documented and agreed to *before* any computer keystrokes are made.

After that, we go to work. In our review of *all* the provided data, we evaluate it thoroughly and *through experience* preliminarily establish what the physical design of a system would *have to be* to meet the project's remediation requirements. In many cases, the Client does not know nor has any opinion what *specific* well design parameters might be, or have to be, to achieve the desired remediation effects – portions of the *Checklist*© are left blank for SPARGE™ to 'figure out'. This is more the norm than not, since as stated before, distributed compressible gas systems are complex and <u>very</u> difficult to design to meet *specific* incremental and total system mass flow rates. In our evaluation, unless specifically directed, we will decide upon the number of 'zones' the well should have (a zone being defined as a section of the well and/or the placement of a section of the well that differs from other adjacent portions of that same well), and all of the appropriate slot size(s) and their percent open area propagation(s). All of the pertinent site data and preferences that the Client wants of his/her remediation system are input into the SPARGE™ program, and when all appropriate and necessary data is input, a simple "Enter" keystroke invokes the program to 'do its thing' (Figure 4, Step #2). Seconds later (in the 'early days' this would be *hours* later), the program finishes its work and provides us with a summary screen of results, having calculated the well's entire performance 'profile' in total and down to the foot-by-foot level. If the computed results of system performance are <u>not</u> what is required by the Client (such as the per-foot injection rate(s) are too small or large, the total quantity of gas injected is insufficient or excessive, or the well needs to be of a different ID to properly function, etc.), one or more previously inputted design parameters are changed and the system is re-calculated. When the SPARGE™ system performance calculation results *match* what is required of the system as specified by the Client, the work is done. The result of this final *100% successful* 'run', which is comprised of a <u>huge</u> numeric database (Figure 4, Step #3), is saved to CD and is then directed to 'post-processing'.

Post-processing of the SPARGE™ derived performance data (Figure 4, Step #4) is what is eventually presented to the Client as easy-to-digest and understand system performance characteristics that his/her system will exhibit when *correctly* installed and operated in the field. These physical characteristics include not only an extensive foot-by-foot numeric array of the system's well screen injection rate(s), pressures, in-well gas velocities, etc., but also accompanying graphs of these same performance variables for easy viewing and to provide a clear understanding of how the system will operate. If found necessary in order to maintain compliance with the Client's system performance requirements, these graphs will be annotated with their particular well screen 'zone'. For example, if to maintain system injection requirements the second 200 feet of well screen is required to have 25% more open area, that section of well screen is defined as a unique 'zone' and its slot design will be modified to achieve this increase in injection rate. Similarly, if, to prevent excessive air being injected under a roadway where contamination is *not* present, a portion of a well needs to have no

[6] An Integrity Engineering, Inc. form entitled Well Design Checklist©

slotting, this section is also defined, and will be presented as, a separate 'zone', from the rest of the well, and it similarly will have a different slot design (in this example, no slotting). To further illustrate this feature of SPARGE™, the lower RH graph of the quantity of air injected in the system presented in the post-processing Figure 5, Step #4, is that of a system of four distinct 'zones', in this case presenting the quantity of air in ACFM per foot of well screen injected for each of these zones. Note how vastly different the incremental injection rates differ among the four zones. In fact, one of the most beneficial design capabilities of SPARGE™ is in its ability to determine how to achieve <u>any</u> desired air injection rate for <u>any</u> well, installed in <u>any</u> type of soil, under <u>any</u> depth of groundwater, and in doing so, specify with precision the *exact* well slotting pattern to achieve <u>any</u> desired injection rate.

<u>No</u> other computational tool, computer program, spreadsheet program or even hand calculation is able to achieve these results time after time, accurately, or even most importantly *defensibly* than SPARGE™. Its value has proven itself in <u>over</u> 1000 *unique successful* system designs in sites located across our country, ranging from very small slant well injection systems measuring at most 35 feet long, to remediation systems employing 24" diameter steel well material, and those systems exceeding ¼ mile in total length. Given the seven-plus years of time devoted to completing the SPARGE™ program and the multitude of source code additions made to advance its engineering capabilities, in retrospect the entirety of effort was well worth it, as innumerable clients, and most importantly, our environment and the flora and fauna it supports, have benefited immensely from its use.

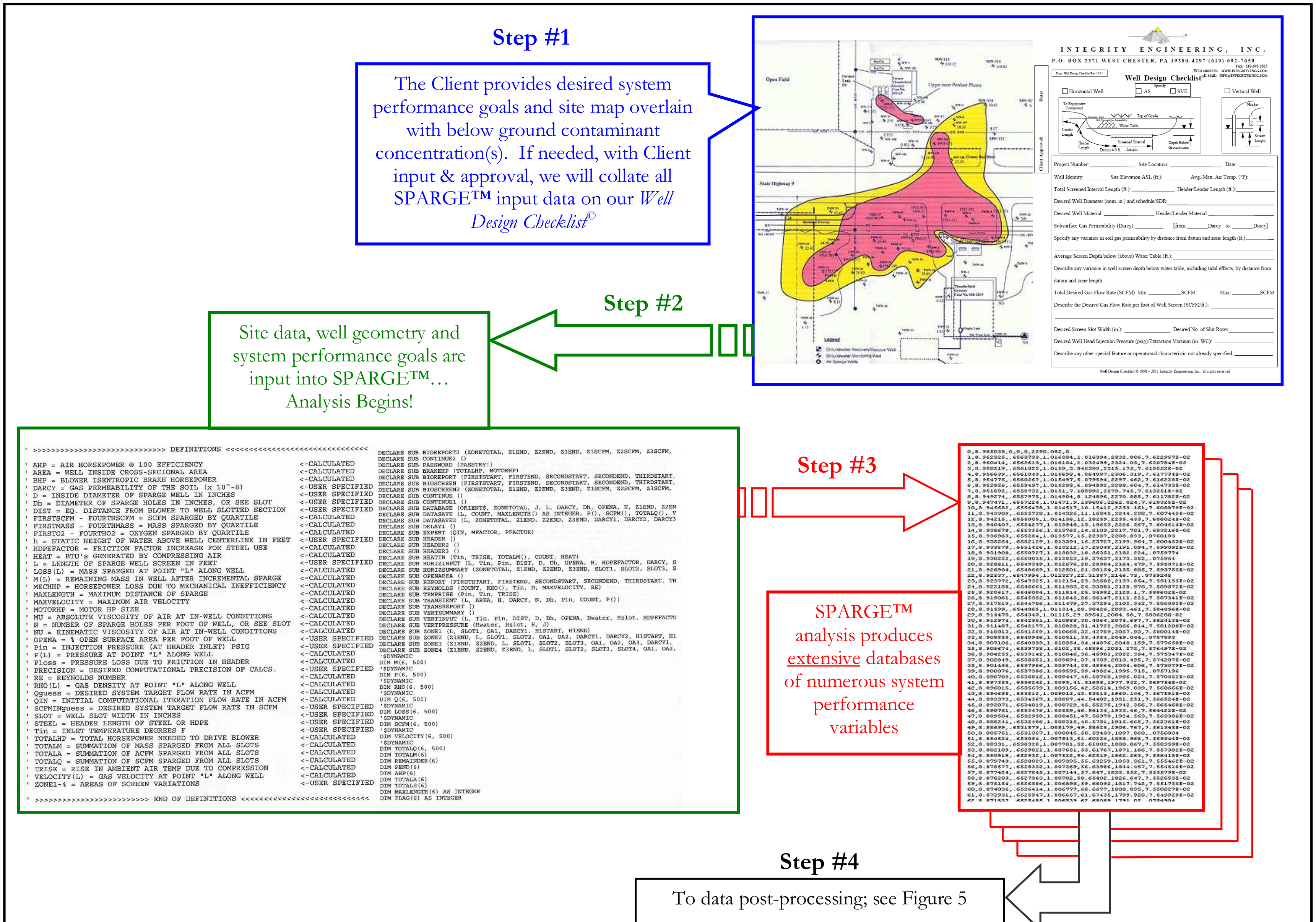
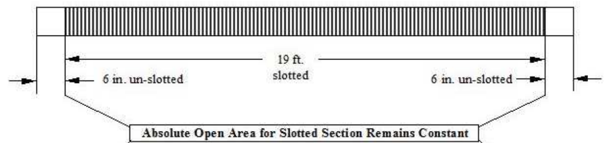


Fig. 4 The SPARGE™ system analysis process from inception and Client request through to completion of a successful system performance analysis.

Step #4 Post-processing

Post-processing of raw SPARGE™ analysis results in <u>extremely</u> accurate system performance predictions, presented in tabular and graphic formats. These include complete Mechanical, Heat Transfer, Thermodynamic system performance & Bioremediation summaries, in-well pressures & air velocities, ACFM & SCFM air volumes sparged per-foot of screen, cumulative air volume sparged over the entire system, and more. When the system is constructed as SPARGE™ directs, that system <u>will</u> perform *exactly* as SPARGE™ has calculated.

Horizontal Sparge Well HAS-1 Slotting Design



Zone ID	Qty of Spools per Zone	Open Area per 20 ft. spool	Open Area per Slotted foot	Slot Width	Slot Arc Length	# Rows Required	Slots per Spool-Row
1	10	15.20 in^2	.800 in^2	.020"	.500"	4	380
2	4	22.80 in^2	1.200 in^2	.020"	.500"	3	760
3	3	7.65 in^2	.403 in^2	.020"	.375"	3	340
4	4	23.00 in^2	1.211 in^2	.020"	.500"	5	460

Example Horizontal Sparge Well-1 Performance

SCREEN DISTANCE (ft)	WELL PRESSURE (psig)	ACFM PER FOOT	SCFM PER FOOT	TOTAL SCFM SPARGED	VELOCITY (fpm)	MASS DISCHARGED PER FOOT
0	9.500987	0	0	0	2124.912	0
1	9.498749	0.335088	0.5120164	0.5120164	2124.912	3.84E-02
2	9.497104	0.3350171	0.5118608	1.023877	2120.492	3.84E-02
3	9.495467	0.334965	0.5117463	1.535624	2116.021	3.84E-02
4	9.493837	0.3349131	0.5116324	2.047256	2111.549	3.84E-02
5	9.492215	0.3348614	0.5115191	2.558775	2107.076	3.84E-02
6	9.4906	0.33481	0.5114062	3.070181	2102.604	3.84E-02
7	9.488992	0.3347587	0.5112938	3.581475	2098.131	3.83E-02
8	9.487391	0.3347077	0.5111818	4.092657	2093.658	3.83E-02
9	9.485796	0.3346569	0.5110704	4.603727	2089.185	3.83E-02
10	9.484209	0.3346062	0.5109593	5.114686	2084.712	3.83E-02
11	9.482629	0.3345558	0.5108489	5.625535	2080.239	3.83E-02
12	9.481056	0.3345056	0.5107388	6.136274	2075.765	3.83E-02
13	9.479491	0.3344556	0.5106293	6.646903	2071.291	0.0382972
14	9.477932	0.3344059	0.5105203	7.157423	2066.817	3.83E-02
15	9.47638	0.3343563	0.5104117	7.667835	2062.343	3.83E-02
16	9.474836	0.334307	0.5103036	8.178139	2057.868	3.83E-02
[illegible]	[illegible]	[illegible]				
[illegible]	[illegible]	[illegible]	0.7497835	224.7232	103.9181	5.62E-02
407	9.259362	0.4956429	0.7497838	225.473	97.08805	5.62E-02
408	9.259365	0.495643	0.7497839	226.2227	90.25796	0.0562338
409	9.259367	0.4956431	0.7497843	226.9725	83.42786	5.62E-02
410	9.259369	0.4956432	0.7497845	227.7223	76.59777	5.62E-02
411	9.259371	0.4956433	0.7497846	228.4721	69.76768	5.62E-02
412	9.259373	0.4956434	0.7497848	229.2219	62.9376	5.62E-02
413	9.259374	0.4956435	0.7497851	229.9717	56.1075	5.62E-02
414	9.259375	0.4956435	0.7497851	230.7215	49.27742	5.62E-02
415	9.259376	0.4956436	0.7497853	231.4713	42.44734	0.0562339
416	9.259376	0.4956436	0.7497854	232.221	35.61726	5.62E-02
417	9.259375	0.4956436	0.7497854	232.9708	28.78717	5.62E-02
418	9.259372	0.4956436	0.7497853	233.7206	21.95709	0.0562339
419	9.259367	0.4956434	0.7497849	234.4704	15.12701	5.62E-02
420	9.259357	0.4956432	0.7497845	235.2202	0	5.62E-02

BIOREMEDIATION DATA BY QUARTILE

	1st QUARTER 0 to 105 ft	2nd QUARTER 105 to 210 ft	3rd QUARTER 120 to 315 ft	4th QUARTER 315 to 420 ft
SCFM	53.22	54.93	60.85	66.22
MASS	3.99	4.12	4.56	4.97
OXYGEN	0.92	0.95	1.06	1.15

RATES OF MASS AND OXYGEN INJECTION IN #/MIN

BIOREMEDIATION DATA BY ZONE

	1st ZONE 0 to 200 ft	2nd ZONE 200 to 280 ft	3rd ZONE 280 to 340 ft	4th ZONE 340 to 420 ft
SCFM	100.69	59.57	14.97	59.99
MASS	7.55	4.47	1.12	4.50
OXYGEN	1.75	1.03	0.26	1.04

RATES OF MASS AND OXYGEN INJECTION IN #/MIN

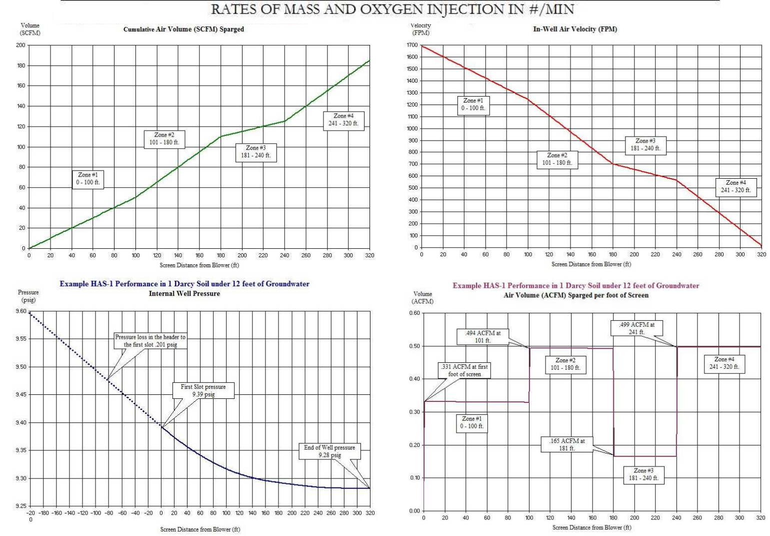


Fig. 5 Compilation of a few of the design & analysis elements completed in a SPARGE™ analysis post-procession effort, including the injection well's complete design, the system's performance database, graphs and Bioremediation data. All are supplied in our Design Report.