Ultimate Recoveries (EURs). This is particularly true in dry shale gas formations where water loading is often one of the most important factors affecting the lifetime of a well. Knowing not only that a well is loading but where along the wellbore the water is coming from could drastically alter the engineering decision making process. Because DAS can accurately identify inflow on the individual perforation level, isolating the water inflow zones/stages by setting packers becomes a reasonable course of action that could be undertaken with a high degree of confidence. Potentially resulting in significantly improved recovery rates and extending the time the well can be flowed without installing tubing. Furthermore, this process is not limited to water loading; other downhole activities such as packing off, salting up and well treatment effectiveness could also be monitored. Going forward research capital should be expended to specifically identify gas and liquid inflow acoustic energy levels. This could be accomplished through laboratory experimentation. Specifically, reservoir representative fluids could be flowed through perforated casing at varying concentrations and flow rates under downhole conditions. The associated acoustic energy levels could then be recorded and this information conglomerated into an acoustic "library".

Developing an acoustic (pressure wave) "library" is in itself a potential area for significant individual contribution. An acoustic library is extremely valuable because it could be implemented across the entire DAS technology spectrum. To develop a library, a statistically significantly sample size of similar DAS data would need to be evaluated. Downhole activities such as a ball landing in a seat to open a sleeve, or fluids leaking around a packer can be identified with non-DAS technologies. However, because these downhole activities also make noises (clunk of the ball landing in the seat and fluid rushing around the packer), it is possible to use the technologies concurrently and associate a downhole activity with a particular acoustic signature (pressure wave). Consequently, it might be possible to develop parts of the library from data collected in actual DAS field trials. However, laboratory established acoustic energy levels would be easier to obtain and possibly more valuable because of their potential to provide insight into downhole acoustic signatures that are not fully understood. Conglomerating and generalizing a statistically significant number of these acoustic signatures would allow for the creation of a library of known downhole sounds. A library of known sounds would be extremely valuable to industry as an integral first step to any viable commercial software package for DAS interpretation. Moreover, the ability to associate an acoustic signature with a downhole activity is absolutely critical if DAS is to be used as a standalone technology with any reasonable degree of confidence.

Gas lift monitoring should also be a significant research focus area. A wealth of flow information can be seen in an acoustic energy plot, including DAS capabilities for gas lift monitoring (**Fig. 4.1**).

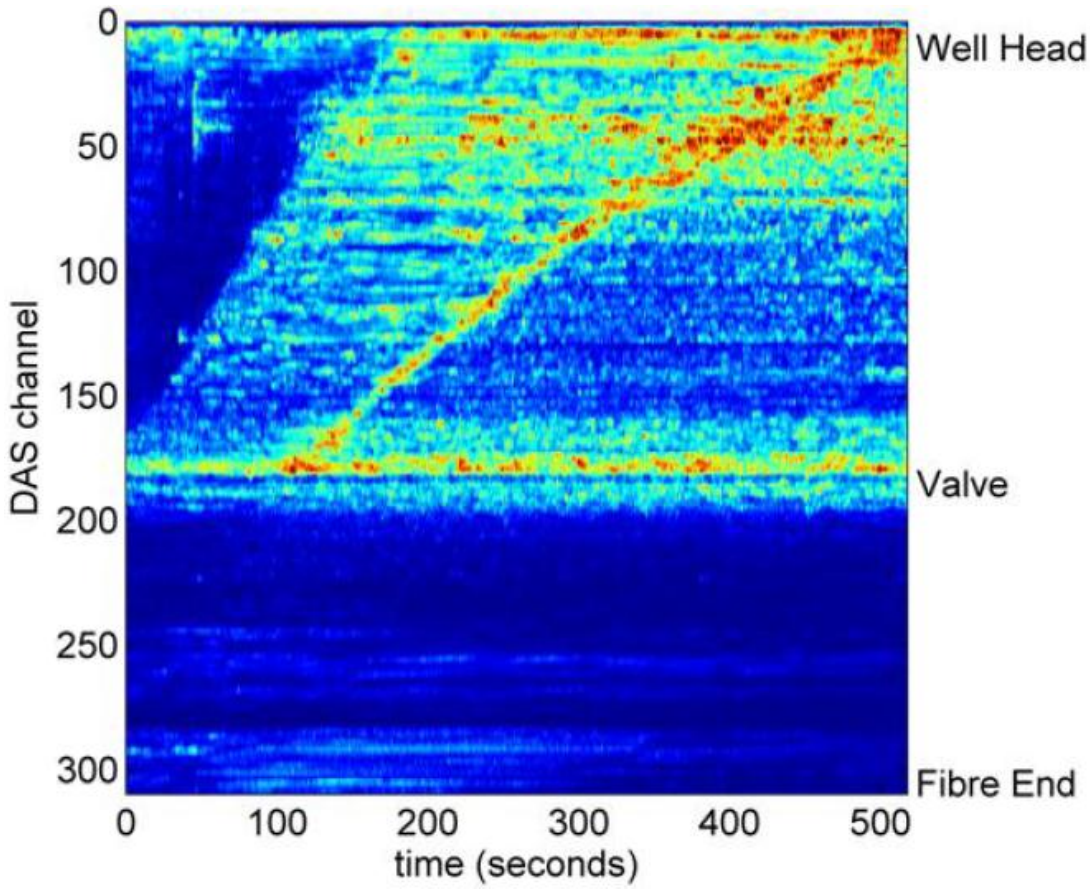

Fig. 4.1—Acoustic energy plot of gas lift valve; red: high, blue: low (Koelman et al., 2012).

As noted by Koelman et al. (2012) a pronounced feature in this particular visualization is the development of multiphase flow starting at the gas lift valve and subsequently reaching shallower levels. This can be seen in the rising gas bubbles marked by the noise wedge starting at the gaslift valve (time 0) and reaching the well head approximately three minutes later (time 180 seconds). A strong localized turbulence can also be seen. This turbulence is most likely associated with a slug of gas that starts at the gas lift valve with a delay of 100 seconds, and propagates upwards at about half the speed of the bubble front. Below the gas lift valve there are lower gas-liquid ratios (blue areas associated with weaker acoustic energy levels). Combining this observed data with knowledge of the well/completion geometries, the flow rates over these single phase flow intervals could be quantified using interpretive methods traditionally applied to noise logging data. Further interpretation and processing of DAS in combination with other technologies could add significant robustness to flow interpretations, particularly as they relate to multiphase flow.

Acoustic energy data like the plot shown above have the potential to drastically alter our understanding of flow in the wellbore. Likewise, a DAS acoustic library would provide a reliable way to identify key downhole activities. However, in order to develop an accurate energy plot, acoustic library, or any other meaningful evaluation mechanism, actual DAS data must be incorporated. Consequently, future DAS research at the university must include the considerable task of obtaining actual DAS data. To combat the significant costs associated with physically acquiring the data, a partnership with industry should be pursued. As noted in Section 3, test wells exist that have yielded substantial amounts of DAS data. The going forward plan of action should include liaising with one or more of the noted companies to determine if they would make any of their DAS data available and if so, addressing the proprietary nature of the data.

It is also important to note that further research to delineate the capabilities of DAS will require, at the very least, a cursory level knowledge of Digital Signal Processing (DSP). This naturally leads to the need to involve persons with knowledge of this particular subset of engineering. Moreover, some form of overlap will occur with electrical/computer engineering and a prudent course of action going forward is to seek out appropriate research partners who can provide expert level understanding in this specific field. In particular, because DAS uses C-OTDR, it will be most beneficial to connect with a research partner whose expertise is in DSP time domain (as compared to spatial domain, frequency domain or wavelet domains). Having expertise in DSP time domain will allow for selection of the correct digital filtering methods necessary to turn acoustic data into a form that will be valuable from a production and completion engineering research standpoint (**Fig. 4.2**).

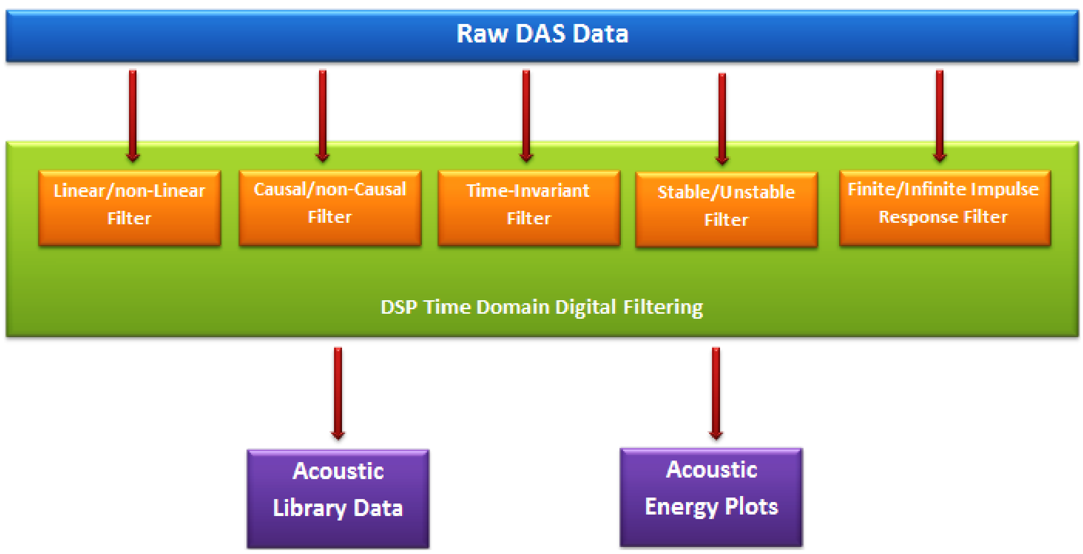

Fig. 4.2—DAS digital filtering progression from raw DAS data to a form useful to researchers.

Collecting and processing acoustic data through time domain knowledge of DSP provides an opportunity to develop a cross-disciplinary collaborative research platform from which many further significant individual contributions can be launched.

5. CONCLUSIONS

5.1 Conclusions

The current state of acoustic fiber monitoring is like the early days of personal computers. There is a lot of excitement about its potential, but it lacks what is known in the electronics business as “killer apps”—widely used applications that would make monitoring pressure waves and vibration in the well a standard business tool (Rassenfoss, 2012). Despite the immature nature of DAS technology, there exists high potential for DAS to aid in the interpretation of wellbore events, particularly those associated with hydraulic fracturing. Many questions still remain regarding the hydraulic fracturing process, especially in the area of multi-fractured horizontal wells. Field trials of DAS suggest that the technology may be useful in finding answers to these questions or in validating the applicability of hydraulic fracturing engineering theories within a particular play (Warren et al., 2012).

DAS has overcome some limitations of other diagnostic tools, notably by the increased confidence of its interpretation and the real time nature of its cursory level observations (Warren et al., 2012). DAS has the potential to fill a much needed gap in the industry’s toolkit for hydraulic fracture diagnostics. Quantitatively comparing the more common tools used to image hydraulic fractures in a multi-fractured horizontal well provides a clear understanding of both the capabilities and limitations of DAS technology (**Fig. 5.1**).

Diagnostic Tool	Feedback Time	Field of Investigation	Limitations
MSM	Semi real time	Far field	• Location uncertainty of frac induced microseismic events • Not indicative of proppant placement
DTS	Real time	NWB	• Fiber survival under harsh conditions • Data resolution was limited to a sample period of about 20 seconds for this well; this is a common limitation of DTS
DAS	Real time	NWB	• Fiber survival under harsh conditions • Currently available DAS processing methods do not provide the focused discrete resolution of all regions of the soundfield that are expected to yield knowledge about the fracturing process, though processing capabilities are rapidly improving
RA Tracer	Post completion	NWB	• Presence of tracer not necessarily indicative of treatment in zone or location of the hydraulic fracture

Fig. 5.1—Quantitative comparison of common tools used to image hydraulic fractures (Warren et al., 2012).

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