30 Future Prospects for SSF Bioreactors

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30.1 The Increasing Importance of SSF

Solid-state fermentation will become of ever increasing importance. The need to use rationally the organic solid wastes that we generate will increase as the increasing world population puts increasing pressure on environmental resources.

In the same manner as the world is coming to understand that, in dealing with liquid wastes, "dilution is NOT the solution to pollution", in the case of organic solid wastes, we can say (even if it does not rhyme so well) that "land-filling or disposal in the environment are NOT the solution to dealing with organic solid wastes". Unfortunately the economic models used in the majority of countries do not adequately penalize the generation and inappropriate disposal of organic solid wastes. Organic solid wastes are often treated as "somebody else's problem". The late Douglas Adams, in the book "Life, The Universe and Everything", one of the books of the "Hitchhiker's Guide to the Galaxy" series, defined "somebody else's problem" as "something that we can't see, or don't see, or our brain doesn't let us see, because we think that it's somebody else's problem" (Adams 1982). Unfortunately, in this case, when we say "somebody else" we mean "our descendants". We bury large quantities of organic solid wastes in the ground or dispose of them inadequately in the environment and wait for the real problem of dealing with them adequately to be faced by future generations. This seems neither sensible nor fair. However, currently, we seem unable or even unwilling to recognize this as a society. As a society we should be dealing adequately with organic solid wastes now and we should feel guilty that we are not doing it. What legacy are we leaving for future generations, not to mention the rest of the ecosystems on this earth?

It may not currently be "economic" to reuse or treat organic solid wastes properly. However, this is a question of the point of view that we use to look at the problem. We need to change our economic models. What price do we put on environmental quality? If we are not careful, sooner or later we are going to be knee-deep in putrefying rubbish. Maybe our difficulty in appreciating the problem is that this will probably not happen in our own lifetimes, but is this really a reason not to worry? We should start thinking harder about organic solid wastes now. We should put a realistic cost on their generation and disposal. The revenue raised can be used to develop and perfect various technologies, including SSF. Of course, the rational processing and treatment of these solids will require a multi-faceted approach. SSF in itself will be only one technology amongst many that will be necessary to cope with the huge volumes that we generate.

Although Holker et al. (2004) do point out correctly that we should be interested in small-scale SSF for specialty products that are induced by the physiological conditions to which the organism is subjected in SSF systems, SSF will also be one of the technologies applied to dealing with the large volumes of organic solid wastes that we generate, so we will need efficient large-scale SSF bioreactors and optimized operating strategies.

30.2 Present State and Future Prospects

It is clear that SSF is not a simple technology. In order for large-scale bioreactors to operate efficiently, we need to base their design and operation on engineering principles. We hope that we have convinced readers of this book that mathematical models of bioreactor operation will be important tools in the design and optimization of performance of large-scale SSF bioreactors. It will also be necessary to extend process control theory to deal adequately with the many complexities that SSF bioreactors present.

Despite our attempts in the present book to bring together the fundamental principles of SSF bioreactor design and operation, we are quite aware that much more work is required. The range of organisms and substrates and the particular challenges that they bring is so great that it is not currently possible to give a generally applicable key to bioreactor selection and operation. In fact, at the moment it would be quite misleading to present anything more specific than the simple key that was presented in Fig. 3.3. Perhaps the best we can do at the moment is to say:

- Do not expect the SSF bioreactor selection and design process to be easy. We hope that your ability to make good judgments in the design and development process has been improved by your having read this book.
- Take advantage of the mathematical models that accompany the present book in order to help you make design and operation decisions. However, do realize that these models are still imperfect tools that need many refinements.
- Despite the advances over the last three decades, the complexity of the SSF system and the phenomena occurring within it are so great that there are significant gaps in our understanding. For example: (1) Although experiments in simplified systems have given us insights into the role of intra-particle diffusion in controlling system performance, we understand relatively little about how these phenomena operate within real solid substrate particles, which are often quite heterogeneous at the microscale; (2) Many SSF processes involve filamentous fungi and we do not sufficiently understand the shear forces within agitated solid beds, the damage they cause to fungal hyphae and the resulting effects on growth of the fungus on the particle; (3) Although particle technology is a well-established area, we do not understand enough about particle be-

havior in solid beds in which fungal hyphae bridge the gaps between particles. As a result of these gaps in our knowledge, there is no guarantee that the application of our best currently available knowledge will lead us to perfectly optimized bioreactors.

We are aware that our book has left many loose ends. Each new large-scale SSF process that is established through the use of a rational approach (that is, through the application of engineering principles rather than through best-guessing or trial-and-error) will contribute to refining our knowledge base.

We envisage a future in which a single computer program can have fast-solving models of several SSF bioreactors embedded, requiring a minimum of information to be input (key bed parameters, heat and mass transfer coefficients, selection of an appropriate kinetic equation for growth and for product formation and input of kinetic parameters, and also parameters of equations describing environmental effects on growth). Such a program might be able to explore optimal design and operational variables for each of various bioreactors, giving outputs of the best performing fermentations for each bioreactor type. Such a program might also enable estimation of capital and operating costs. However, it might be as much as 20 years before a useful version of such a model is available. The amount of work required, not only to advance the theoretical framework of SSF bioreactor design and operation, but also to expand the database through experimental research and development, should not be underestimated!

So SSF bioreactor design remains a challenge. We hope that this book has not only contributed to your understanding of the issues and your ability to apply them, but has also stimulated you to contribute to further developments in this area.