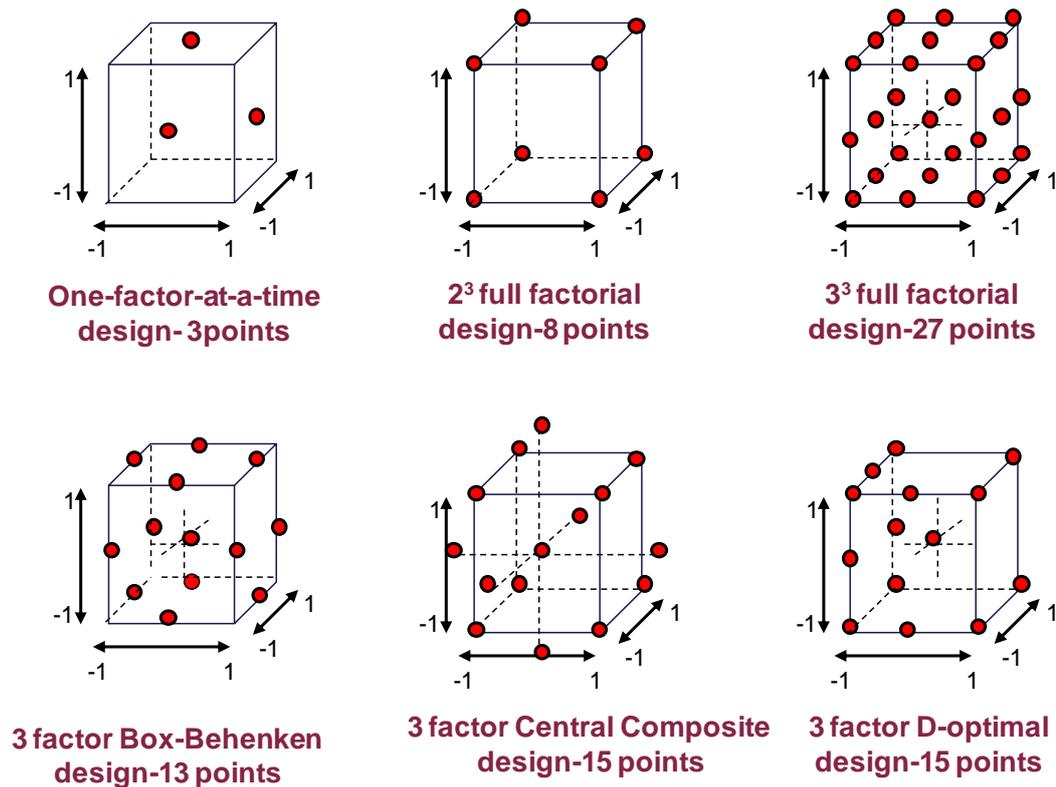


## APPENDIX A *Experimental Design*

Details on various designs are explained comprehensively by Box and Draper (1987) and Myers and Montgomery (2000). Figure A.1 depicts configuration of examples of classical designs for three factors.



*Figure A.1: Configuration of various types of experimental design for three factors.*

**Full Factorial Designs:** two levels full factorial design requires  $2^k$  samples, i.e. examine each of  $k$  factors at two levels and simulated all combination effects, while three levels design require  $3^k$  experiments. In general,  $m$  levels per factor results in  $m^k$  samples. It may be possible to use mixed levels for factors

**Fractional Factorial Designs:** are based on the fraction of full design, and consists of  $m^{k-p}$  runs to reduce the cost.

**Plackett-Burman Designs:** in using them the influence of  $k$  parameters can be studied with only  $k+1$  simulations.

## Appendix A

### Quadratic Designs:

**1) Central Composite Designs:** are made up of: 1) a two-level full factorial, 2) an additional points or star in the middle of the factor domain, and 3) a central point. For  $k$  parameters CCD is constructed with only  $2^k+2k+1$  samples (typically for number of factors of less than 10). When the number of factors is equal or larger than 10, instead of full factorial, a two-level fractional factorial of resolution **III, IV, V** are used to make the design economical. Then for  $k$  parameters CCD is constructed using  $2^{k-p}+2k+1$  simulation runs. Typically  $p=1$  for  $k=10$  and then as 'p' increases sequentially 'k' also increases, i.e.  $p=10$  for  $k=20$ . In this thesis, resolution **V** was used. In resolution **V** main effects are aliased with 4-factor interactions, and 2-factor interactions are aliased with 3-factor interactions. We generated these designs using Matlab7.0.1 statistical toolbox. There is limitation for the value of 'p' in the Matlab7.0.1 (p could be only 0, 1 and 2). For factor numbers larger than 12, CCD design of resolution **V** were constructed using Design-Expert 8.0.3 software.

**2) Box Behnken Designs:** they are three level fractional factorial designs of  $3^{(k-p)}$  runs. These designs do not have simple design generators. They have complex confounding of interaction. Initially Box and Behnken proposed these designs for the factor numbers of 3-7, 9-12, or 16. For other number of factors; the designs were not originally tabulated by Box and Behnken, however, they could be found in several statistical packages (e.g. Matlab7.0.1 or Design-Expert 8.0.3) but there is some discrepancy between design constructed with these packages although they are declared using the same method of Box and Behnken. In this thesis BBD design was constructed using Design-Expert 8.0.3 software.

**3) D-optimal Designs:** computer optimization routines are used to construct these designs. The number of experimental runs could be specified by user. In this thesis Matlab7.0.1 software was also used to generate D-optimal designs, and the number of experiment runs was specified to be equal to the number of runs of CCD designs, for the same number of parameters. D-optimal designs are those that minimize the volume of the confidence ellipsoid of the regression estimates of the response surface model coefficients. We generated these designs using Matlab7.0.1 statistical toolbox (for more details see Statistical Toolbox of Matlab software).

## *Appendix A*

**Latin Hypercube Sampling (LHS):** in this design for **k** number of factors, **n** number of design points ( $n \geq k$ ), and **m** levels of factor, each column of the design matrix is a random permutation of the factor levels. LHS designs are straightforward, however, the orthogonal LHS designs are not easy to generate, yet the tabulated forms of them are available for some number of factors (Cioppa and Lucas 2005). They are recommended for relatively large number of factors and they have good space filling properties.

**Resolution in factorial designs (R):** it indicates the level of confounding also called aliasing or confusion between linear terms and interactions. Engineers are generally interested in designs of resolution **III**, **IV**, and **V**. Resolution **V** designs unreservedly estimate all linear terms and all two factor interactions with no confounding with each other, however, they are confound with at least three-factor interactions or higher-order terms, hence, they are the most useful, but can still be quite expensive. Resolution **IV** designs freely estimate all linear terms, but they are confounded with at least three-factor interactions, and confounding exists among the set of two factor interactions, nevertheless, they are very useful for sensitivity studies, because of their low cost. Resolution **III** designs are designs in which linear terms are confounded with two-factor interactions, and are tricky to use but can be useful since they are very inexpensive.