Bifurcation of Flow Patterns in Glass Manufacturing Process

Satyajit Wattamwar, Siep Weiland, Ton Backx

I. INTRODUCTION

Spatial discretization of Distributed Parameter Systems (DPS) is done by means of Finite Volume (FVM) or Finite Element methods (FEM) and Galerkin or Petro-Galerkin projection techniques and they are simulated in Computational Fluid Dynamic (CFD) software environment. Such discretization approximates process behavior reasonably well, but it leads to very high dimensional process models. Such process models can not be easily used for online plant optimization and control. Model Order Reduction (MOR) is therefore an important step before proceeding to control design [1]. The method of Proper Orthogonal Decomposition (POD) is widely used for deriving smaller dimensional models from the First Principle Model (FPM). Models identified by POD techniques are not well equipped for a process whose uncertain parameters undergoes extreme behavior [2]. Industrial Glass Manufacturing Process (IGMP) that we are studying shows geometric parameter dependence which leads to a kind of bifurcation in the fluid flow pattern. Such type of process behavior can not be easily captured in models identified from POD technique.

II. INDUSTRIAL GLASS MANUFACTURING

Industrial Glass Manufacturing (IGM) is usually carried out in a very large furnace. A 2D view of the tank is shown in Figure 1. The flow pattern of glass decides the residence time of the glass which in turn decides its quality. Most of the process variables like temperature, velocity, pressure, viscosity are interacting with each other. Due to this interactions the control of the tank has to be done carefully. Variables of interest are temperature distribution and velocity profiles in the furnace. The temperature maintained inside the tank varies between $1400-1650\ ^0$C. The IGMP shows large variation in the time scales. Timescales of heat input from the top refractory material of the furnace is in the span of couple of minutes whereas timescale of pull rate change is in hours. Process residence time show combined behavior of ideal Continuous Stirred Tank Reactor (CSTR) and ideal Plug Flow Reactor (PFR). The transport of physical quantities in GMP can be approximated with reasonable accuracy by modeling it as a set of nonlinear Navier-Stokes equations. Due to very high process temperature and viscous nature of glass, limited sensors can be placed, that too in the bottom wall of the tank.Some details about mathematical modeling of glass can be found in [3].

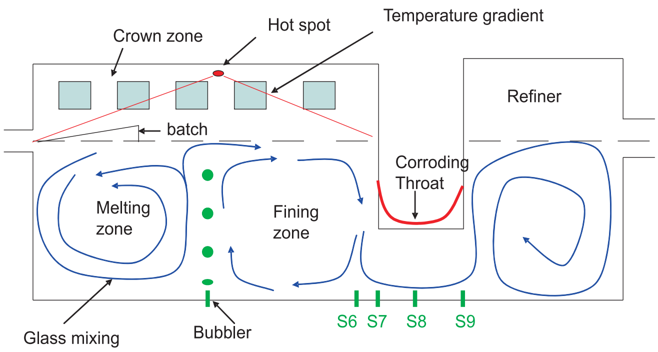

Fig. 1: Industrial Glass Manufacturing

Our current research focus is to identify reduced model which can capture the very slow geometric parameter change that takes place in real $3D$ tank in the form of throat or dam wall corrosion.This corrosion results into back-flow of molten glass from refining to fining section. Such back-flow behavior causes change in the temperature distribution in fining and melting zone and which ultimately leads to product quality loss. For $2D$ tank (slice of $3D$ tank) we observe the bifurcation behavior i.e the occurrence of back-flow somewhere between throat height of 0.2m and 0.3m.

III. MODEL REDUCTION

Computationally efficient models are obtained from CFD models of IGMP by using Proper Orthogonal Decomposition (POD) and subspace method identification techniques. POD is used to captures the spatial information in the form of POD basis functions while the temporal information is captured in POD modal coefficients. This gives computationally faster models with reasonable accuracy and it is referred as POD-SID approach. To identify the process parameter value (corrosion level of throat) we propose a hybrid kind of detection mechanism [2]. This mechanism is based approximation of real process by two POD-SID reduced models, one approximates process before bifurcation and other after bifurcation.

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All authors are with Dept. Of Electrical Engg., Technical University of Eindhoven, P.O. Box 513, 5600 MB Eindhoven, The Netherlands s.wattamwar@tue.nl

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