Chapter 6
Conclusions and Future Scope

Arc heater system plays an important role in the development of safe high power Hydrogen Fluoride / Deuterium Fluoride lasers. Although researchers have used arc plasma devices for initial performance of CW chemical lasers, but technical details on the development of arc plasma devices for laser applications is not available in the open literature. Moreover, control, sensors and data acquisition aspects for hostile arc-driven HF/ DF chemical laser are not addressed anywhere as most of these systems have been developed for defense applications. The R & D activity in this field demands the development of Arc heater and also a special custom-built data acquisition and control system which meets the on line operational requirements for thorough understanding of the arc heater and the laser. The work presented in the thesis focuses on the development of 50 kW arc heater system, which is utilized for the development of kW level HF/ DF Laser. The mathematical modeling of arc heater geometry for chemical laser application has also been carried out and results have been validated with the similar work of Favalli et al.

The developed 50 kW arc heater has been integrated with the laser tunnel that includes plenum, nozzle, optical cavity, diffuser, evacuation and scrubber system etc. Interfacing of arc heater and laser tunnel with the dedicated Data Acquisition system has been carried out to study the detailed performance for its suitability for laser applications. Major conclusions of the present work are summarized below:
• For a kW HF laser, the requirement of arc heater is that can support a, mass flow rate of 7-8 g/s of gas mixture that consists of 5-6 g/s N\textsubscript{2} and 1 g/s of H\textsubscript{2} and SF\textsubscript{6} and stagnation temperature 2000- 2300 K. Keeping in view various factors including the efficiency of arc heater device, it is estimated that a 50 kW arc heater will be sufficient for these applications.

• Mathematical modeling studies of arc plasma heater geometry suitable for chemical laser applications with commercially available software COMSOL has been carried out. Numerical modeling results of arc discharge phenomenon relevant for HF/ DF chemical laser are discussed in details to emphasize the importance of computational work. The comparison of simulation results with studies available in the literature has been made to validate the design adopted in the present studies [115].

• Hardware development of 50 kW arc heater and the associated diagnostic system has been carried out. Also the development of components such as supersonic nozzle, laser cavity, diffuser and vacuum dump etc required for ultimate interfacing of arc heater with laser tunnel are also discussed.

• The major sub systems such as power system, gas supply system, cooling system and DAS for safe operation of 50 kW are heater were developed. Commercially available welding generators / welding rectifiers, which have drooping V/I characteristics have been used as a power source for arc heater. Gas flow rates of SF\textsubscript{6}, O\textsubscript{2}, and H\textsubscript{2} have been controlled through orifice operating under choked conditions [116].
- Data acquisition and control system have been realized with ADAM 500 series cards. This system consists of subsystem Kernel with plug in modules. The subsystem Kernel handles all software functions between the field devices and the host computer, including signal conditioning, data conversion, calibration, alarm monitoring, internal diagnosis and communication. The control panels were designed & developed for measurement and control of different arc related parameters such as voltage, current, flow, pressure & temperature etc from single control console. The control panels have been made operational for safe working of arc heaters [117-119].

- A vacuum dump of 25 m$^3$ capacity has been installed which is evacuated using roots Blower pump of 2000-5000 m$^3$/h pump capacity. It takes around 20 seconds to blow down 25 m$^3$ vacuum dump to few torrs.

- The associated sub-systems of 50 kW arc tunnel such as supersonic nozzle, cavity/resonator, diffuser & evacuation system were designed & developed.

- Performance evaluation studies for 50 kW arc heater in terms of temporal variation of voltage and current and also the voltage – current characteristics for different flow rates of nitrogen and argon have been carried out. The results are in compliance with the literature.

- The laser tunnel sub systems were interfaced for feasibility study of lasing with arc heater as part of HF laser system.

- Performance evaluation of Laser tunnel has been carried out keeping in view the requirements of various flow rates, pressures at various places like mixing chamber, cavity, post diffuser for realization of a kilowatt HF laser. The observed
Mach no of 4.5 – 5 corresponding to total flow rate of about 7 g/s is very much conducive to lasing.

- The entire process is operated remotely from a control room away from the system. The main system consisting of the arc heater, plenum, nozzle, Laser cavity and diffuser is located in a specially designed room, which is isolated. The vacuum dumps are kept in the open area surrounded by walls of adequate height. The vacuum pump and scrubber are also housed in separate rooms equipped with exhaust fans.

- The safety interlocks has been implemented keeping in view the human safety. Further a scrubber system capable of neutralizing the outlet gases has been developed for flow rates upto 40 g/s that corresponds to a kilowatt HF / DF laser. The gases, coming out of the laser system consist of hydrogen fluoride, sulfur dioxide, un-reacted hydrogen and possibly, some quantities of fluorides of sulfur. These gases pass through a diffuser, and are released to atmosphere after treatment in a scrubber, where the acidic gases are removed.

- Toxic gas monitors have been installed at strategic locations in the working area to take care of any leakage in the system. The gas monitors are for fluorine, sulfur dioxide, hydrogen and hydrogen fluoride (HF). All the monitors are capable of detecting the respective gases well below their TLV limits and raising an alarm at selected concentration. In addition the response of the detectors is recorded in the data acquisition system. Safety measures for handling of hazardous gases have been implemented through the dedicated DAC system for safe operation of arc-driven HF laser tunnel.
Four papers out of the present work has been published in international referred journals/conference.

**Future Scope**

HF/DF lasers have great potential for industrial and military applications because of its high efficiency and potential for power scale up. These applications, however, require development of compact, cheap, high beam quality HF/DF systems, which in turn requires development of many technologies related with the improvement of this laser. One of the most important aspects, which need to be looked into, is the compact power supply for the arc heater. Though in the present studies, commercially available systems available for welding applications has been used, however with the availability of components like MOSFETs and IGBTs, the supply has to be developed around these components to make the system more reliable and compact. Other system that requires to be developed is an efficient pressure recovery system so that the system can be exhausted to atmosphere. Further Electric arc discharges can also be used as energy sources for high temperature research, material processing, fabrication of nano-particles and nano-structured films. New cutting, welding and spraying torches as well as other new arc applications such as waste destruction may be developed on the basis of this work. The mathematical modeling concepts can be used for optimization of tungsten inert gas welding processes (TIG/GTAW), as well as plasma arc welding (PAW).

Industrial applications require continuous operation preferably for few hours without any power degradation. The HF system suitable for these applications should be capable of delivering high power up to few kilowatts with large duration that is possible only through atmospheric pressure recovery technology.
Keeping in view the potential of HF/DF and the encouraging results obtained in the present studies, following research studies can be undertaken in future.

- The developed 50 kW arc tunnel can be utilized for optimization of lasing parameters. Various parameters like gas feed rates, arc heater power, Mach no. optical resonator optics can be fine tuned for a kilowatt output power.

- Development of a compact 50 kW arc heater with state of the art power supply system can be taken to upgrade the present system.

- Power scaling up of the HF laser up to 10 kW can be taken up based on the experience gained in the present studies. The scaled up system can be used for demonstration of directed energy weapons concept for the defence services.

- Technologies associated with Atmospheric pressure recovery techniques can be pursued so that the system can become not only portable but can run continuously for larger durations for industrial applications.