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Contents

Application of Advanced Manufacturing Technologies In Indian SMEs: Opportunities And Challenges

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ABSTRACT

Small and medium enterprises (SMEs) have played a very important role in an Indian economy. However, there are many factors inhibiting the adoption of new technologies especially related to advance manufacturing technologies in the competitive and challenging world today. It is important to identify the challenges; SMEs face with regard to adopting new manufacturing technology. In order to survive in a long run, this study identifies challenges faced by SMEs in India and approach to overcome challenges by using these advanced manufacturing technologies. Findings have been further validated with the help of a case study.

Keywords: ***Small and medium enterprises (SMEs), Challenges, Advanced Manufacturing technologies (AMTs), India.***

1. INTRODUCTION

Small and medium enterprises (SMEs) are regarded as the backbone of economic growth in all countries because they account for 80 percent of global economic growth [15].According to singh et al., [33] domestic market under protective environment as available for small and medium enterprises in the era prior to economic reforms. According to Lange et al., [18] SMEs plays an important role in creating employment and income. An important issue with respect to the strategic development and growth of SMEs is the enabling role that can be played by advanced manufacturing technologies (AMTs) such as CAD/CAM, EDI, and MRP II [10]. For the economic stability of any nation, survival and success of SMEs is crucial. SMEs play an important role in export and employment generation in developing countries [1]. According to Sharma and Bhagwat [31] a prerequisite for successful operations of small and medium enterprises are- availability of right kind of information at right time. According to Singh [34], after liberalisation and globalisation of economy in India, SMEs are under intense pressure since the markets are now facing competition from countries like China, Taiwan, and Korea which have emerged as low cost manufacturing destinations, a distinction earlier enjoyed for long by Indian SMEs. According to (Singh et al., [32] in manufacturing sector, SMEs act as specialist suppliers of components, parts and sub-assemblies to larger companies because these items can be produced at a cheaper price compared to the price large companies must pay for in-house production of the same components. However, poor quality of input products can adversely affect the competitiveness of these larger organizations.

According to Forsman [8] Current literature suggests that SMEs may differ from larger companies by a number of key characteristics, e.g. resource and knowledge limitations, lack of money, reliance on a small number of customers and need for multi-skilled employees. According to Rahman [28] SMEs are defined by a number of factors and criteria, such as location, size, age, structure, organization, number of employees, sales volume, worth of assets, ownership through innovation and technology.

OBJECTIVE OF THIS STUDY

The purpose of this study to find the problems and challenges faced by SMEs in adopting advanced manufacturing technologies and the strategies to decrease barriers to AMTs adoption and to validate it with the help of a case study. The next section reviews the literature for the identification of challenges faced by SMEs, followed by a case study on an Indian SME and finally the conclusion of the study.

2. LITERATURE REVIEW

In present scenario quality is one of the most important drivers for global competition. Customer and intensifying global competition increases demand for better quality. To meet the challenge of this global competition, many businesses have invested substantial resources in adopting advanced manufacturing technologies [7] . New manufacturing strategy often involves the adoption of new technologies and changes in the organisational structures and practices, such as just-in-time (JIT) and total quality management (TQM) that may result in radical changes in the way business is conducted [43].

Why SMEs need AMTs?

According to Zammuto and O'Connor, [44] AMTs refer to a group of technologies that include computer-aided design (CAD) and engineering systems, materials resource planning systems, robotics, computer controlled machines, flexible manufacturing systems, automated materials handling systems and computer-integrated manufacturing systems. Introduction of new products can occur more frequently through use of computer-aided design and manufacturing (CAD/CAM), since the design lead times may be shortened. Flexible manufacturing systems (FMS) and automated materials handling systems reduce set-up times and other interruptions so that products flow more smoothly and faster through the plant [14].

A number of manufacturing SMEs have scanned the technological environment in order to lower their operating costs, increase productivity and quality, and respond to the increased requirements of their customers, a number of SMEs have made sizable investments in adopting advanced manufacturing technologies such as computer-aided design and manufacturing (CAD/CAM) and flexible manufacturing systems (FMS) [20]. SMEs have also invested in implementing advanced computer-integrated manufacturing applications such as MRP II and ERP to plan, command, and control manufacturing resources and operations, and link them with other organizational systems [22]. Taken together, these technologies and applications constitute AMTs that are assimilated and integrated to a varying degree in the SME's operational and managerial environment [30,21]. Increased requirements for competitiveness, innovation, quality, flexibility, and information processing capability has led many small and medium-sized enterprises (SMEs) to make sizable investments in adopting advanced manufacturing technologies (AMTs) such as robotics and computer-aided manufacturing [20].customers, a number of SMEs have made sizable investments in adopting advanced manufacturing technologies such as computer-aided design and manufacturing (CAD/CAM) and flexible manufacturing systems (FMS) [20]. SMEs have also invested in implementing advanced computer-integrated manufacturing applications such as MRP II and ERP to plan, command, and control manufacturing resources and operations, and link them with other organizational systems [22]. Taken together, these technologies and applications constitute AMTs that are assimilated and integrated to a varying degree in the SME's operational and managerial environment [30,21]. Increased requirements for competitiveness, innovation, quality, flexibility, and information processing capability has led many small and medium-sized enterprises (SMEs) to make sizable investments in adopting advanced manufacturing technologies (AMTs) such as robotics and computer-aided manufacturing [20].

Challenges Faced by SMEs

According to Ongori and Migiro [26], the social goal of equitable income is served by SMEs. However a multiple challenges are faced by these categories of enterprises. There are a number of solutions suggested to minimize the challenges along with adoption of manufacturing technologies to boost efficiency and competitiveness. Reliable and continuously improving business and manufacturing processes capacity of the firm are maintained to meet challenges appear to be a key condition for ensuring its competitiveness in the long run [19]. Major challenges for SMEs are human resource development [12] ,up gradation of technology[16], new product development [36]and finally managing its supply chain through collaboration and partnerships with customers, suppliers, distributors, competitors, and other organizations such as consulting firms and research centres [37,2]. According to Vos [42], managers of SMEs have poor skills in reflecting upon their companies strategically. Constraints may have been by their due to the scarcity of resources, flat organizational structure, lack of technical expertise, paucity of innovation, occurrence of knowledge loss, etc [9].

In addition, challenges facing SMEs are lack of managerial skills, finance, market information and commercial intelligence gathering have been identified [27,11]. SMEs are also faced with problems of small markets, inadequate regional integration, poor infrastructure, bad governance, legal and administrative hindrances and failure to access credit [25]. In spite of support from government and private initiative, many SMEs face problems are experienced by SMEs during economic downturns along with economic progress [17].

Conceptual Framework

The conceptual framework has been developed to facilitate the process of AMTs adoption. As shown in figure 1 this framework is divided into four elements. These elements are the forces for AMTs adoption; barriers to AMTs adoption, AMTs tools and outcome of AMTs adoption. The driving forces include the globalization, change in technology, competition, market advantages .These forces insist managers to adopt AMT tools in their business processes. However, SMEs have failed to adopt AMTs in their business processes because of restraining forces Ongori and Migiro[26].These restraining forces are the barriers including lack of adequate infrastructure, lack of resources, lack of technological advancement, lack of security, lack of effective training to employees, lack of managerial skills. SMEs managers need to put in place strategies to minimise these challenges. The government should develop policies in encouraging AMTs adoption in SMEs. In addition, the non-governmental organizations will encourage SMEs in terms of financing than to buy AMT tools and developing their manpower. The barrier stops them from rising further and putting them in a difficult position to face the new challenges that are emerging from globalization[26].

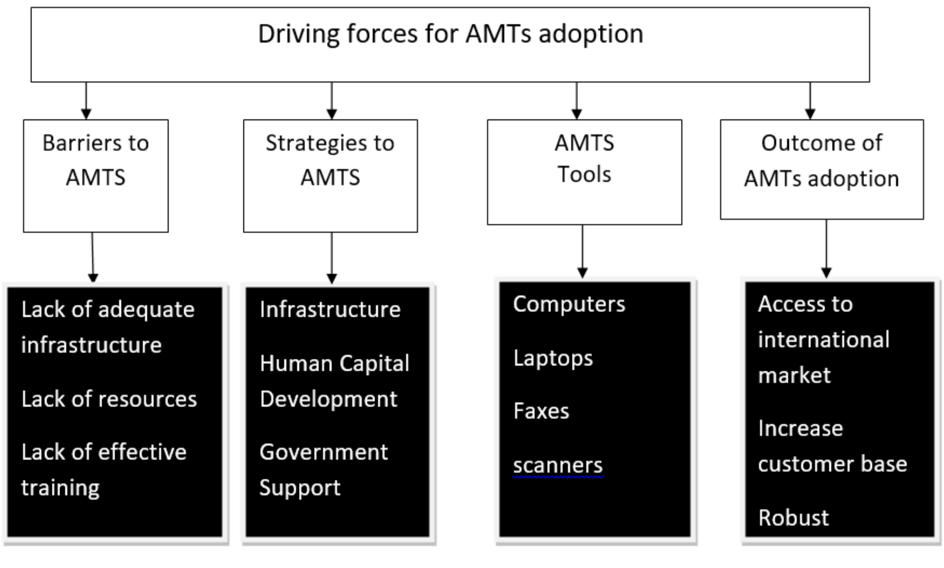

FIGURE 1: Framework for AMTs adoption

SOURCE: ONGORI AND MIGIRO (2010)

Drivers to AMTs adoption

To survive and compete with large companies SMEs has compelled to adopt AMTs in their business process and also due to impact of globalization [31]. A study conducted by Sharma and Bhagwat [31] indicates that the bloodline of any business operating unit disregarding of its size is the flow of information in an organization.

Extant researchers have found that the driving forces for AMTs adoption by SMEs include competition, organization's AMTs readiness, customer/supplier dependency, external pressure to adopt, need to improve customer services and increase in sales [40,41]

According to Crag and King [5], lack of information system knowledge is one of the strongest restrain factors for small and medium enterprises. Most SMEs employees do not have the required knowledge on information technologies; it becomes inconvenient for them to adopt AMTs in their business. Besides, adoption of AMTs theoretically unsuccessful to benefit SMEs due to several challenges from the external business environment.

Strategies to decrease barriers to AMTs adoption

The government interventions therefore tend to framework AMTs policy which is crucial in building infrastructure, investing in research and development, facilitating technological transfers, creating science parks and creating a legal framework [39].

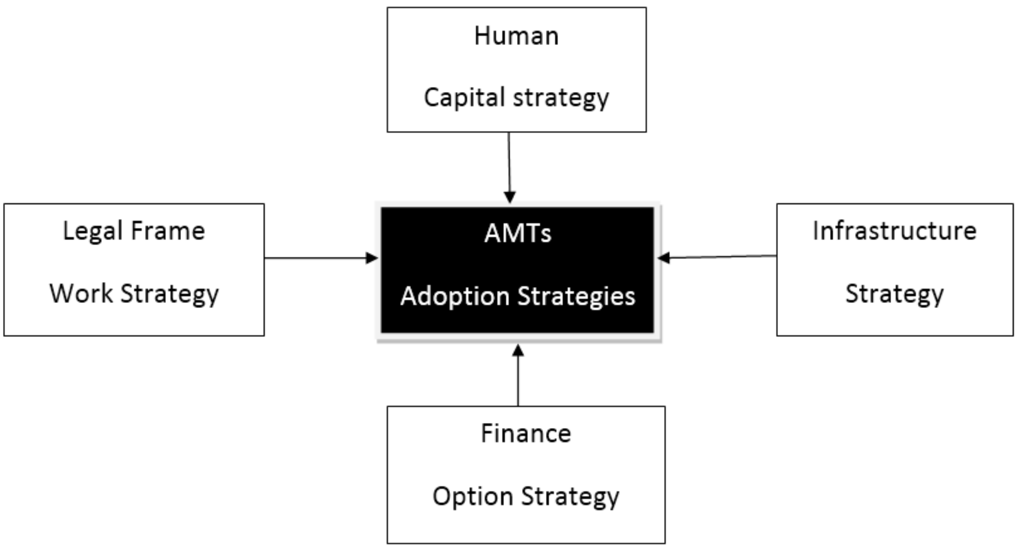

FIGURE 2: Strategies to decrease barriers to AMTs adoption

SOURCE: ONGORI AND MIGIRO [26]

In addition, there are AMTs policies which provide tax incentives for investing in AMTs, subsidising AMTs training for SMEs, thus creating incentives for e-procurement and other online activities. Lastly, there should be an SMEs policy, for instance, in providing SMEs financing and business consulting services, simplifying registration procedures, providing tax breaks and in creating incubation centres [6,23]. The government should boost SMEs in AMTs adoption process by increasing affordability of AMTs through grants, credits, leasing options and tax incentives [39,6]

Benefits to AMTs adoption

The adoption of AMTs is important for the well organized administration of SMEs, and in the delivery of quick services. For use in the organization for decision making AMT tools enable information to be electronically stored, accessed, delivered and retrieved[29,3]. To lead organizational successfulness AMTs enable SMEs to have access to robust / tough business information [13]. In addition, strengthening accountability systems of business enterprises, AMTs play an important role. For instance, the performance of employees in SMEs can be tracked and budget processes can be transparently executed [4]. AMTs adoption in SMEs to a certain degree can decrease greatly the operational costs by decreasing material, procurement and transaction costs, resulting in lower prices for intermediate and finished goods, and they can also use more and better information to improve the value of their output [24].

CASE STUDY: To illustrate the framework considered in this study, a case study in Indian context has been considered.

Profile of Organisation (ABC ltd)-

ABC was established in the year 1969.It is located in Faridabad (Haryana), India. It is major supplier to most leading OEM's worldwide. They have Strategic and technical alliance with major international players in the industry. It is a largest integrated manufacturer of Fluid transmission products (FTPs). It supplies to all domestic automotive players-Mahindra & Mahindra, Tata Motors, Kirloskar, Fiat. It also supplies to most of the multinational- Maruti, Johndere, New Holland, Ford Fiat and General Motors. It is the manufacturers of Rubber Hoses and Assemblies, Metal tube Assemblies.

Challenges faced by ABC Ltd.

Based on interaction with top management, major challenges for this organisation are identified. They are as follows:

- Inadequate resources as well as other technologies
- Lack of adequate technical infrastructure
- Lack of specialised and effective training
- Information gap between marketing and production functions as well as lack of funds for implementing expensive software such as ERP system
- Lack of effective market research
- Insufficient awareness of latest technologies.
- Legal and administrative hindrances
- Difficulties in accessing loans and other forms of financial assistance
- Lack of trained and skilled manpower
- Lack of security
- High cost of internet connectivity

Strategies adopted by ABC Ltd.

Major strategies adopted by ABC ltd are:

- To increase infrastructure through launching share in the market.
- To increase technical knowledge, it will tie up with parallel industry or hire a consultant.
- Provide training to their employees by experienced employee to the same or hired expert from outside
- Use websites, email, and telephone for filling information gap between different departments, customers & suppliers.
- To appoint manpower for market research through survey of the customer asking their performance.
- To arrange motivational lectures through experts who have latest knowledge about technologies.
- To appoint a legal advisor to the administrative issues

TABLE 1: Status of technologies implementation in ABC ltd

Major technologies used and their status with observed benefits are given in table no.1

TECHNOLOGY APPLIED	STATUS	BENEFITS
1. CAD (COMPUTER AIDED DESIGN)	Implemented in Design (Technical and Engineering Drawing)	a) Increase the productivity of designer b) Improve the quality of design c) Improve communication through documentation
2.CAM (COMPUTER AIDED MANUFACTURING	Implemented in use of a computer to assist in all operations of a manufacturing plant, including planning,	a) Creates a faster production process and components. b) Tooling with more precise dimension and material c) High quality parts d) Integrated with DNC system for delivering and management of files to CNC machines on shop floor.
3.MRP (MATERIAL REQUIREMENT PLANNING)	In process of implementing in organizing inventory and production planning	a) Timely delivery of manufactured goods to your customers. b) Availability of the right materials required for production, on time c) Optimal use of manufacturing resources
4. ROBOTICS	Implemented in welding but in process of implementing in material handling and in assembly.	a) Productivity and Profits b) Reduced cost c) fears about loss of labour d) Improvement in quality
5.FMS(FLEXIBLE MANUFACTURING SYSTEMS)	Unaware of using this technology	a) Greaterlabour productivity. b) Greatermachine efficiency. c) Improvedquality. d) Increasedsystem reliability. e) Reduced parts inventory.
6. CIM (COMPUTER INTEGRATED MANUFACTURING)	Aware but not using due to cost. This can be used in Design, planning and	a) Ability to create automated manufacturing processes b) Manufacturing is faster. c) Prone to less error
7.INFORMATION TECHNOLOGY (RFID)	Unaware but this technology can be used in inventory control, work in process	a) RFID tags can be read hundreds at a time. b) Tracking of goods c) Fast, rugged and reliable
8.INFORMATION AND COMMUNICATION TECHNOLOGIES	Unaware of using this technology but can be used in process, package,	a) Access to international market. b) Increases the productivity process
9.AUTOMATED MATERIAL HANDLING SYSTEMS	Aware but not using .This can be used in material handling	a) Total elimination of manual handling b) Safe and efficient product flow c) Clean and efficient production system
10. ERP (ENTERPRISE RESOURCE PLANNING)	Implemented in inventory management and now in process of implementing in	a) Improve productivity b) Increase efficiency c) Improve productivity

3. CONCLUSION

This Study found that Adoption of Advanced Manufacturing Technology is an important to survive in globally competitive market. SMEs play an important and crucial role in the economic growth of the country. SMEs are facing many challenges which hinder SMEs to adopting advanced technologies in their business process. These challenges are lack of adequate technical infrastructure, lack of specialised and effective training, insufficient awareness of these technologies, lack of technological skill and global competition, managerial skills, legal and administrative hindrances, lack of security and trust. Most SMEs owners/managers do not understand the benefits of AMTs adoption. The strategies adopted to decrease these barriers are: To increase infrastructure through launching share in the market. Provide training to their employees by experienced employee to the same or hired expert from outside. To appoint manpower for market research through survey of the customer asking their performance etc. Therefore Adoption of AMTs by SMEs will make them more successful to survive in this competitive scenario.. Findings of the study helps to understand benefit to industry by increasing efficiency of employees, increasing productivity of the industry, increasing quality of the product, increasing customer satisfaction, reduce fatigue of the employees and reduce production cost and time. This study will help to understand the advantage of the application of advanced technologies with respect to traditional technologies

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A Review on Zeolite - Water Adsorption Refrigeration System

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ABSTRACT

This paper aims to provide the current state of the zeolite water adsorption refrigeration systems. A comprehensive literature review has been conducted and it was concluded that this technology, although attractive, has limitations regarding its performance that seem difficult to overcome. Therefore, new approaches were identified to increase the efficiency and sustainability of basic adsorption cycles. Present review shows that there are adsorption cycles that can used not only to serve the refrigeration, but also to meet the demand for economy, energy conservation and environmental protection.

Keywords: zeolite - water adsorption; working pairs; solar power adsorption refrigeration

1. INTRODUCTION

In recent decades, increasing cooling demand in the industrial and residential sectors aggravates energy consumption leading to a corresponding deterioration of environment from higher fossil fuel utilization. Cooling by the conventional vapor compression chillers consumes much electricity. There are many villages where electricity is presently unavailable or far from sufficient. Such areas also need refrigeration machine in order to preserve food and vaccines. To overcome this problem, compression system powered by electricity is replaced with a thermal compressor driven by low grade thermal energy like solar energy, geothermal energy etc. The main attraction to the solar adsorption refrigeration is that its working fluids satisfy the Montreal protocol on ozone layer depletion and the Kyoto protocol on global warming. Choosing the most appropriate adsorbent-adsorbate pair is one of the important factors determining the efficiency of the adsorption refrigerator. Since the desirable lowest adsorption temperature for the adsorption refrigerator is room temperature, the boiling point should be preferentially higher than 20˚C.

However, the vast application of this green technology is bottle necked by low coefficient of performance (COP) and relatively larger foot-print. The existing adsorption chillers operate well below the theoretical Carnot limit. Meunier et al. [1]

2.1 THE PROCESS

2.1.1. Solar Power Adsorption Refrigeration System

In solar power adsorption refrigerator, cooling is achieved by using adsorption – desorption principle. In this system water is used as working fluid and synthesized highly porous silicon compound (Zeolite 4A) is used as adsorbent. When cool (at night) zeolite acts like a sponge for soaking water vapour and when heated during the sunning day the water vapour is desorbed. The system operates under a partial vacuum, the water vapour moves with high efficiency under low pressure. At the desorption temperature of water, water vapour begins to desorb from the Zeolite. Thus the receiver act as a boiler and the water vapour leaves through the perforated holes on the duct to the condenser. This water vapour is condensed as heat is given off by the heat exchanger. The resulting water runs into a sealed storage tank. The liquid water in the storage tank (an evaporator) adsorbs heat from the space to be cooled and is converted into water vapour. Since the system is sealed under very low pressure, the remaining water in the storage tank freeze's into ice. This ice will melt slowly during the next day thus providing sustained cooling at reasonable constant temperature. **Omisanya et al.** [2] discussed the design and production of a solar powered zeolite-water adsorption refrigerator using concentrating parabolic collector (CPC) was done. An array of two CPCs was designed, and performance tested using commercial pelletized zeolite 4A as adsorbent and water as refrigerant. The experimental results were presented in terms of values of system temperature and cooling performance coefficient. It was found that hourly instantaneous COP ranges from 0.2 to 2.5 while the hourly insolation ranges from 34W/m2 to 345W/m2. Evaporator temperature of 11°C and maximum adsorber temperature of 110°C was recorded. The minimum daily – hourly mean COP of 0.838 with the corresponding maximum COP value of 1.48 was achieved. Meteorological condition was also recorded with an average total daily-hourly isolation of 170W/m2. **Fernandes et al.** [3]reported that the paper aims to provide the current state of the art of solar adsorption refrigeration systems operating with the single-bed intermittent cycle (also known as basic cycle). Since, there were the limitations regarding such technologies, therefore, new approaches were identified to increase the efficiency and sustainability of basic adsorption cycles, like the development of hybrid or thermal energy storage adsorption systems. It showed that there were simple adsorption cycles which could be attractive alternatives not only to serve the needs for air-conditioning, refrigeration, ice making, thermal energy storage or hybrid heating and cooling purposes, but also to meet the demands for energy conservation and environmental protection. **Miguel Ramos et al.** [4] shows some of the experimental evaluations of a prototype solar refrigerator, based on an intermittent thermodynamic cycle of adsorption, using water as refrigerant and the mineral zeolite as adsorber. No condenser was applied in this system, because the solar regeneration was made in the ambient air for the regeneration, a SK14 solar cooker was considered. The cold chamber, with a capacity of 44 liters, was aimed for food and vaccine conservation. The evaluation of the EG Solar prototype refrigerator showed that the intermittent water – zeolite adsorption cycle is appropriate for a refrigerator for food conservation in rural areas where no electricity is available. **Parash Goyal et al.** [5] discussed on the fundamental knowledge of the adsorption systems and presented a comprehensive literature review of the past efforts in the field of solar energy utilization. Adsorption refrigeration technology provides noiseless, non-corrosive and environment friendly operation by the utilization of low grade heat sources, especially solar energy. A plethora of adsorption cooling systems had been developed but still these cooling systems were not ready to compete with the traditional vapor compression cooling systems. A survey showed the limitations of adsorption system regarding their technical and economic aspects which were difficult to overcome. **Yadav et al. [6]** discussed about Peltier effect with which one can cool a specific area without using compressor which take a huge consumption of electricity. This system is driven by solar energy using solar plates, battery, transformer peltier module and heat sink. The analysis showed that for the prevalent conditions the compressor less AC is significantly more economical to own and operate than the conventional AC. In spite of a slightly higher initial cost, the thermoelectric AC proves to be more economical, mainly due to its significantly lower operating cost.

2.1.2. EXPERIMENTAL SETUP

The solar powered adsorption refrigerator was designed to achieve cooling by operating on adsorption - desorption principle. This system has no moving parts. Water is used as working fluid and synthesized highly porous silicon compound (Zeolite 4A) is used as adsorbent. The system consists of the following components as shown in figure – 2-solar compound parabolic concentrating collectors (CPC), the condenser, the flood evaporator, airtight cap (valve) and control valve. It is based on the fact that when cool (at night) the Zeolite acts like a sponge soaking up or adsorbing the water vapour and when heated during the sunning day the water vapour is desorbed or released.

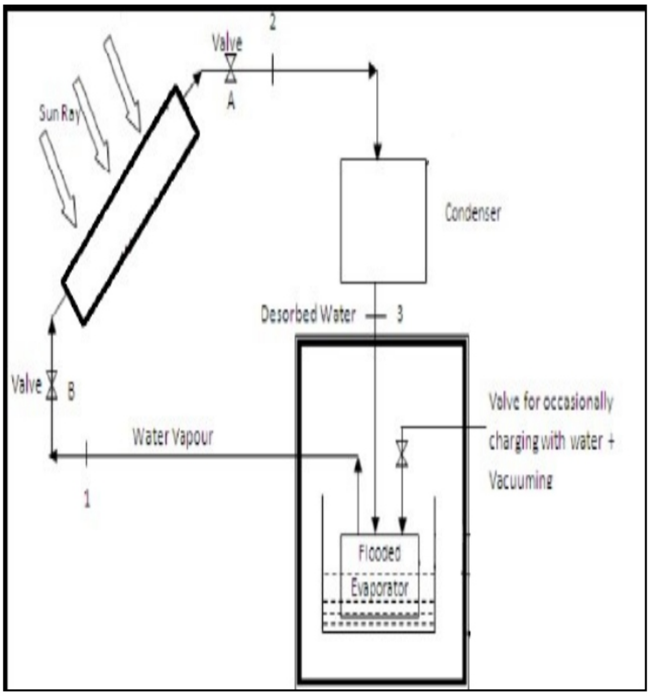

Figure 1: Adsorption Refrigerator Design Flow Diagram

The system operates under a partial vacuum, the water vapour moves with high efficiency under low pressure. At the desorption temperature of water, water vapour begins to desorb from the Zeolite. Thus the receiver act as a boiler and the water vapour leaves through the perforated holes on the duct to the condenser. This water vapour is condensed into water droplet as heat is given off by the heat exchanger; as depicted in the flow diagram (Figure 1). The resulting water runs into a sealed storage tank which is situated inside the refrigerator compartment. During the night, Zeolite is cooled close to ambient temperature and start adsorbing water vapour. The liquid water in the storage tank adsorbs heat from the space to be cooled and is converted into water vapour. Since the system is sealed under very low pressure the remaining water in the storage tank freeze's into ice. This ice will melt slowly during the next day thus providing sustained cooling at reasonable constant temperature.

2.2 COEFFICIENT OF PERFORMANCE

The coefficient of performance is defined as the ratio of the total refrigeration effect produced in the system to the total energy required for this effect.

$$\text{C.O.P.} = \frac{\text{Refrigeration Effect}}{\text{Total Energy Input}}$$

2.3 SELECTION OF THE WORKING PAIR

There are various types of adsorbent–adsorbate working pairs that can be used in adsorption refrigeration systems. Since the performance of the system depends upon the choice of working pair, therefore, working pair should be selected very carefully. The selection of the working pair depends on the temperature of the heat source, the desired characteristics of the refrigeration system, the properties of the working pair constituents and the affinity between them (which depend on the chemical, physical and thermodynamic properties of the substances), and even on their cost, availability and environmental impact.

2.3.1. CHOICE OF ADSORBATE

The adsorbate, or refrigerant, must fulfill the following requirements –

- Evaporation temperature below 0˚C (for refrigeration purposes; it can be higher in the case of air-conditioning applications);
- Small molecular size so as to facilitate the adsorption effect;
- High latent heat of vaporization and low specific volume (when in liquid state);
- High thermal conductivity;
- Low viscosity;
- Thermally stable with the adsorbent in the operating temperature range;
- Chemically stable in the operating temperature range;
- Non-toxic, non-corrosive and non-flammable;
- Low saturation pressures (slightly greater than atmospheric pressure) at normal operating temperature;
- Absence of ecological issues, unlike common refrigerants.

The most commonly used refrigerants are ammonia, methanol and water. Water and methanol operate at sub-atmospheric saturation pressures at the operating temperatures needed, and any infiltration of ambient air immediately results in system malfunction. In the case of ammonia, small leakages can be tolerated for some time, but its saturation pressure of 13bar at a condensing temperature of 35˚C is highly demanding. Ammonia is toxic and corrosive, while water and methanol are not, but methanol is flammable. Water is the cheapest and most thermally stable adsorbate but it can not be used for cooling purposes below 0˚C.

2.3.2. CHOICE OF ADSORBENT

The most important features for choosing a suitable adsorbent are:

- Ability to adsorb a large amount of adsorbate when cooled to ambient temperature, to yield a high cooling effect;
- Desorption of most of the adsorbate when heated by the available heat source;
- Low specific heat;
- Good thermal conductivity, to shorten the cycle time;
- Non deterioration and adsorption capacity losses over time or with usage;
- Non-toxic and non-corrosive;
- Chemically and physically compatible with the chosen refrigerant;
- Low cost and wide availability.

The most important point is that the adsorbent must be porous enough to adsorb large refrigerant quantities, but this result in low thermal conductivity, which limits the performance of the refrigeration system. Therefore, there must be a compromise between the high porosity required for rapid vapor diffusion and the high density required for good thermal conductivity. The most commonly used adsorbents are activated carbon, zeolite and silica-gel. Activated carbon provides high adsorption and desorption capacities.

2.3.3. WORKING PAIRS

Adsorbent–adsorbate working pairs their characteristics, performances, advantages and disadvantages. The most commonly used working pairs are: zeolite–water, silica-gel– water, activated carbon–methanol and activated carbon–ammonia. Silica-gel–water is ideal for solar energy applications due to its low regeneration temperature, requiring low grade heat sources, commonly below 85C. Moreover, water has the advantage of having a greater latent heat than other conventional refrigerants.

Activated carbon-Methanol pair

Activated carbon–methanol is one of the most common working pairs in adsorption refrigeration systems. It also operates at low regeneration temperatures (care must be taken since regeneration temperatures above 120˚C promote the decomposition of methanol), while its adsorption-evaporation temperature lift is limited to 40C. This pair is also characterized by its large cyclic adsorption capacity, low adsorption heat, low freezing point and high evaporation latent heat of methanol. However, activated carbon has a low thermal conductivity, acting like a thermal insulator and causing decrease in the system's COP and like the silica-gel–water pair, activated carbon–methanol also operates at vacuum conditions. Besides, methanol must be used with caution due to its high toxicity and flammability. One of the first records of application of the activated carbon– methanol pair in adsorption refrigeration systems occurred in France, by the early1980s,when Delgado et al. [7]. In the same decade, Pons and Guilleminot [8] developed a solar ice-maker prototype. Mhiri and ElGolli [9] described the study of a solar adsorption refrigerator working with the activated carbon–methanol pair, in order to build an industrial system.

Activated carbon–ammonia pair

In the late 1980s, Critoph [10] developed a simple low cost solar refrigerator operating at high pressure with the activated carbon– ammonia pair, which was recommended by the United Nations for vaccine storage in poor regions. A coil shaped evaporator immersed in water was used, and its temperature reached -1˚C during the experimental tests, producing 3–4 kg of ice per day, with a net solar COP of 0.04. Already in this century, Oliveira [49] designed and tested an adsorption refrigerator comprising tube and shell heat exchangers as reactor, which could be powered, for example, by solar energy. The system produced 1.2 and1.6 kg of ice per kg of adsorbent daily, when the regeneration temperature was 75˚C and 85˚C, respectively. The solar COP was 0.08 in both cases. **H. Ambarita & H. Kawai [11]** discussed about solar-powered adsorption refrigeration cycle with generator filled by different adsorbents has been tested by exposing to solar radiation. Four different experiments of solar-powered adsorption cycle were carried out, they were with, generator filled by 100% activated alumina (named as 100AA), by a mixed of 75% activated alumina and 25% activated carbon (75AA), by a mixed of 25% activated alumina and 75% activated carbon (25AA), and filled by 100% activated carbon (100AC). Each case was tested for three days. The results showed that the average COP of 100AA, 75AA, 25AA, and 100AC was 0.054, 0.056, 0.06, and 0.074 respectively. The main conclusion drawn was that the pair of activated carbon and methanol is better than activated alumina.

Zeolite-water pair

The application of this working pair in refrigeration systems emerged in the late 1970s, mainly through the pioneering work of Tchernev, who developed a 100 dm^3 solar refrigerator with a 1m^2 solar collectors [11, 12]. More recently, Lietal. [13] presented the simulation results of a solar refrigerator, in which the zeolite is placed inside the evacuated tubes of the solar collector. The adsorbent can reach 200˚C and the overall system performance is relatively high compared to the previous solar adsorption refrigerators, reaching theoretical solar COP values higher than 0.25 **Wei-Dong et al. [14]** a modified adsorption cooling module with a working pair of 13X zeolite-water used for engineering truck air-conditioning driven by engine waste heat is presented in this paper. The cycle operating characteristics of the module at different cooling powers were analyzed and discussed and it was found that the performance of the cooling module was having a strong coupling with exterior ambient parameters such as the heat source (T_{hs}), ambient temperature (T_a), air velocity (v) and air relative humidity (φ). Results indicated that the demonstrated cooling module had a good performance, and the minimum evaporating temperatures corresponding to the cooling powers of 2.0W and 10.5W are 0.7˚C and16.2˚C, respectively, under the conditions of $_{Ths}$ at 325˚C, T_a at 18˚C, φ at 70%, and natural convection. **Kyaw Thu et al. [15]** discussed, an environment-friendly adsorption chiller using Zeolite FAM Z01–water pair as opposed to the conventional silica gel and water pair was used. Zeolite was thinly coated onto the surfaces of fin-tube heat exchanger for faster rates of heat and mass transfer. The performance of zeolite-based chiller was evaluated in terms of total heat input, cooling capacity, and coefficient of performance (COP) with respect to heat source temperature and adsorption/desorption cycle time where an optimal operational zone can be determined: (i) hot water inlet temperatures range from 65˚C to 85˚C, (ii) adsorption/desorption cycle times of 200–300 s at optimum cooling and COP. **D. Baker et al.[16]** In this Experimental investigation of a natural zeolite–water adsorption cooling unit, a thermally driven adsorption cooling unit using natural zeolite–water as the adsorbent–refrigerant pair has been built and its performance investigated at various evaporator temperatures. Under the experimental conditions of 45˚C adsorption, 150˚C desorption, 30˚C condenser and 22.5˚C, 15˚C and 10˚C evaporator temperatures, the COP of the adsorption cooling unit is approximately 0.25.and the maximum average volumetric cooling power density (SCPv) and mass specific cooling power density per kg adsorbent (SCP) of the cooling unit are 5.2 kW/m^3 and 7 W/kg, respectively. R. Georgiev et al. reported in the study, an adsorption cooling module. The module was designed to operate on ecological materials: zeolite and water. The adsorption refrigeration module was thermally powered by a solar collector system and study of the dynamics of temperature parameters defines the cooling and condensation processes in the adsorption refrigeration module. Its potentials for cooling (air conditioning) were investigated. In the zone of the evaporator, refrigerant temperatures in the range of 1–5°C were obtained for 6.5 hours. During cooling (adsorption) temperature of the zeolite rose by 8.5°C. For desorption of water vapour (refrigerant) heat from thermal solar systems 78-80°C was used. **P. P. Chachad & S. Bhadane [17]** in their paper showed the usage of Zeolite 4A for application in adsorption refrigeration frameworks. The refrigeration framework model comprises of two steel chambers, one containing Zeolite and the other containing refined water at a weight relating to the room temperature, three transports funnels having one valve each. The most reduced evaporator temperature obtained was 9.8°C with a C.O.P of 0.4.

Silica-gel water pair

In 1986, a refrigeration system with a $0.25m^2$ flat plate solar collector containing silica-gel was developed in Japan [18]. To improve the collector heat transfer, it was divided into several blocks with square fins, leading the temperature of the adsorption bed to a maximum of 80˚C. A solar COP of 0.2 was attained. At the beginning of the current century, in Switzerland, **Mayor and Dind [19]** built a portable solar adsorption refrigerator proto- type. The collector has a surface area of $1m^2$, containing the silica-gel inside its tubes. The cold box is thermally insulated by vacuum panels, and the system contains a special valve that replaces the manual valves from the previous prototypes. This refrigerator system has the capacity to cool down 30 K a mass of 2.5 to 3.7 kg of water in a desert climate.

3. SUMMARY OF REVIEW

Working pair	Reference	Application	Solar COP	$T_{e\,(˚c)}$	Type
Activated carbon-methanol	Delgado et al. [6]	Ice maker	0.15(syst.)	-5˚C	Simulation
	Pons and Guilleminot [7]	Ice maker	0.10-0.12 (net)	-5˚C	Experimenta
	Mhiri and El Golli [8]	Ice maker	0.14-0.15	-5˚C	Experimental
Activated carbon–	Critoph [9]	Ice maker	0.04(net)	-1˚C	Experimental
	Oliveira [21]	Ice maker	0.08	-10˚C	Experimental
Zeolite–Water	Tchernev [11]	Refrigerator	0.15		Experimental
	Omisanya et al. [2]	Water cooler	0.8-1.5	11˚C	Experimental
	Li et al. [13]	Refrigerator	0.25-0.3		Simulation
Silica-gel water	Sakoda and Suzuki [19]		0.2	5˚C	Simulation
	Mayor and Dind [20]	Ice maker	0.10-0.15	5˚C	Simulation

4. CONCLUSION

This paper presents an extensive review of the state of the art of solar refrigeration systems operating with the basic adsorption cycle. The operation principle, covering its main components, thermodynamic aspects and performance assessment is explained in this paper. It also consists of the most commonly used adsorbate–adsorbent working pairs, presenting some specific requirements, advantages and disadvantages in their selection. Combining the adsorption cycle with other refrigeration cycles also improves the overall performance of the system. It also includes the experimental study on adsorption characteristics and performance of solar-powered adsorption refrigeration cycle with generator filled by activated alumina, activated carbon, and a mixed of activated alumina and activated carbon have been carried out. The conclusion found in this experiment is even though the adsorption capacity of activated alumina is higher than activated carbon, but for solar radiation as a heat source the pair of activated carbon is better. This is because the isobaric-desorption pressure of activated alumina is higher than activated alumina. The mixed adsorbent of activated alumina and activated carbon does not show a better COP than the pure activated carbon.

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Automatic Turn-off Indicator System For Vehicle Safety In Two Wheelers

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A B S T R A C T

Confusion in driving may lead to inconvenience, or even fatal accidents. Indicator lights have provided us a mean to signal other vehicles the direction where we wish to turn so that these vehicles can give us time and space to do so. In two-wheelers, however, the indicator light does not turn off automatically once the turn has been maneuvered. The driver, may forget to turn off the indicator manually. This leads to confusion and inconvenience to the other drivers. The project deals with an innovative system, which can be applied to all the two-wheelers, to automatically turn off the indicator light once the turn is made.

Keywords – ***Indicator light, Automatic, Turn Off, Two Wheelers, Safety***

1. INTRODUCTION

Each day 377 people in India die in a traffic accident. More than 1.2 million people in the world die each year on the roads. Two wheelers account for 25% of total road crash deaths. One of the main cause of accident is turning of vehicle without any indication or wrong indication. Using wrong indicator leads to confusion in the following traffic which also results in congestion on roads. By implementing the auto turn-off indicator system this confusion can be eliminated.

A considerable expansion was seen in the sales volume of the scooter segment during 2014-15 as far as the two-wheelers were concerned. The domestic motorcycle sales volume moved up to 10 percent, whereas the scooter segment recorded a growth of 30.7 percent in sales volume. In the past 2-3 years, around a dozen new scooter brands have been introduced in India. But the motorcycle segment lags behind in this regard. This is due to the fact that the recently launched gearless scooters cater to the needs of both men and women, while motorbikes are a segment preferred by men only.

As far as mechanism for detecting the turn of vehicle and switching off the indicator is concerned, the accelerometers gives a good information for detecting it. These measure the acceleration in the different coordinates, through these measurements change in angle or position could be detected.

Using an accelerometer and analyzing statistical data to detect when a vehicle turns can be implemented in a way so as to avoid confusion on the road and help in safety of the driver and passengers.

One approach to turn off the indicator is by using a timer that shuts off the indicator at a predetermined time. However, it is not a robust system as each driver turns the indicator on at a different time depending on the traffic congestion and style of driving. An intelligent system able to detect the angle of the vehicle is better option as it is capable of applying in any scenario.

1.1 Literature Review

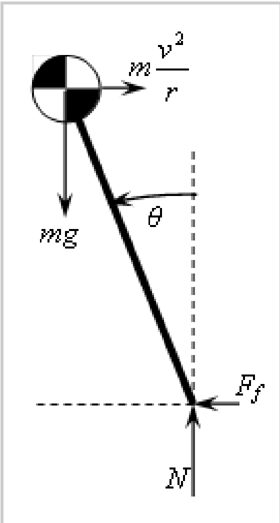

Figure 1 : Forces in turning of a two-wheeler vehicle

The forces, both physical and inertial, acting on a leaning bike in the rotating reference frame of a turn where *N* is the normal force, F_f is friction, *m* is mass, *r* is turn radius, *v* is forward speed, and *g* is the acceleration of gravity.

$$\theta = \arctan\left(\frac{v^2}{gr}\right)$$

Equation 1 : Relation of angle with speed and radius of curvature

Where, v is velocity of vehicle

g is acceleration due to gravity

r is radius of curvature

θ is angle of lean

$$r = \frac{w\cos(\theta)}{\delta\cos(\phi)}$$

Where, w is wheelbase

δ is steer angle

ϕ is caster angle

The finite width of the tires alters the actual lean angle of the rear frame from the ideal lean angle. Actal lean angle increases with tire width and decrease with center of mass height. Assuming that the speed of the vehicle is approximately 10-20 kmph, the value of angle can be detected by an accelerometer easily.

<table>
<tr><th>S.No.</th><th>Speed

(in kmph)</th><th>Steer Angle (in degrees)</th><th>Lean Angle (in degrees)</th></tr>
<tr><td>1</td><td>10</td><td>5</td><td>2.7</td></tr>
<tr><td>2</td><td rowspan="4">10</td><td>10</td><td>4.5</td></tr>
<tr><td>3</td><td>15</td><td>6.76</td></tr>
<tr><td>4</td><td>20</td><td>8.99</td></tr>
<tr><td>5</td><td>25</td><td>11</td></tr>
<tr><td>6</td><td rowspan="4">20</td><td>2</td><td>4.44</td></tr>
<tr><td>7</td><td>5</td><td>10.99</td></tr>
<tr><td>8</td><td>10</td><td>21.24</td></tr>
<tr><td>9</td><td>15</td><td>30.24</td></tr>
<tr><td>10</td><td rowspan="2">30</td><td>2</td><td>9.9</td></tr>
<tr><td>11</td><td>5</td><td>23.6</td></tr>
</table>

2. EXPECTED OUTCOME

When the system is turned on, the accelerometer starts to take readings in small intervals along the angle of the vehicle with respect to the ground.
As soon as the vehicle starts truning, the accelerometer detects the change in angle, and turns the indicator off one the vehicle restores to normal position.

3. DETAILS OF APPARATUS

3.1 Microcontroller – Atmega 32

The Atmel®AVR®ATmega32 is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture. By executing powerful instructions in a single clock cycle, the ATmega32 achieves throughputs approaching 1 MIPS per MHz allowing the system designer to optimize power consumption versus processing speed.

The device is manufactured using Atmel's high density nonvolatile memory technology. The On chip ISP Flash allows the program memory to be reprogrammed in-system through an SPI serial interface, by a conventional nonvolatile memory programmer, or by an On-chip Boot program running on the AVR core. The boot program can use any interface to download the application program in the Application Flash memory. Software in the Boot Flash section will continue to run while the Application Flash section is updated, providing true Read-While-Write operation. By combining an 8-bit RISC CPU with In-System Self-Programmable Flash on a monolithic chip, the Atmel ATmega32 is a powerful microcontroller that provides a highly-flexible and cost-effective solution to many embedded control applications.

The Atmel AVR ATmega32 is supported with a full suite of program and system development tools including: C compilers, macro assemblers, program debugger/simulators, in-circuit emulators, and evaluation kits.

Figure 2. ATmega 32 Microcontroller

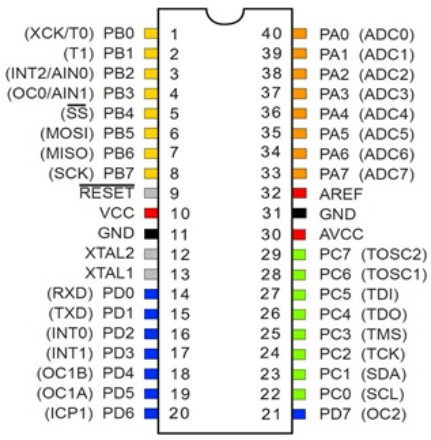

Figure 3: ATmega 32 Pin Diagram

3.2 Accelerometer – ADXL335

The ADXL335 is a small, thin, low power, complete 3-axis accelerometer with signal conditioned voltage outputs. The product measures acceleration with a minimum full-scale range of ±3 g. It can measure the static acceleration of gravity in tilt-sensing applications, as well as dynamic acceleration resulting from motion, shock, or vibration. The user selects the bandwidth of the accelerometer using the CX, CY, and CZ capacitors at the XOUT, YOUT, and ZOUT pins. Bandwidths can be selected to suit the application, with a range of 0.5 Hz to 1600 Hz for the X and Y axes, and a range of 0.5 Hz to 550 Hz for the Z axis. The ADXL335 is available in a small, low profile, 4 mm × 4 mm × 1.45 mm, 16-lead, plastic lead frame chip scale package (LFCSP_LQ).

The ADXL335 is a complete 3-axis acceleration measurement system. The ADXL335 has a measurement range of ±3 g minimum. It contains a polysilicon surface-micromachined sensor and signal conditioning circuitry to implement an open-loop acceleration measurement architecture. The output signals are analog voltages that are proportional to acceleration. The accelerometer can measure the static acceleration of gravity in tilt-sensing applications as well as dynamic acceleration resulting from motion, shock, or vibration.

The sensor is a polysilicon surface-micromachined structure built on top of a silicon wafer. Polysilicon springs suspend the structure over the surface of the wafer and provide a resistance against acceleration forces. Deflection of the structure is measured using a differential capacitor that consists of independent fixed plates and plates attached to the moving mass. The fixed plates are driven by 180° out-of-phase square waves. Acceleration deflects the moving mass and unbalances the differential capacitor resulting in a sensor output whose amplitude is proportional to acceleration. Phase-sensitive demodulation techniques are then used to determine the magnitude and direction of the acceleration.

The demodulator output is amplified and brought off-chip through a 32 kΩ resistor. The user then sets the signal bandwidth of the device by adding a capacitor. This filtering improves measurement resolution and helps prevent aliasing.

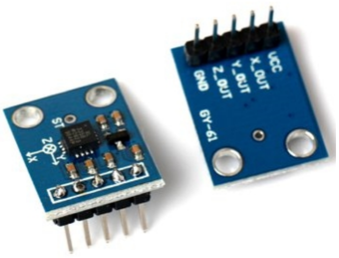

Figure 4: ADXL 335 Accelerometer

The ADXL335 uses a single structure for sensing the X, Y, and Z axes. As a result, the three axes' sense directions are highly orthogonal and have little cross-axis sensitivity. Mechanical misalignment of the sensor die to the package is the chief source of cross-axis sensitivity. Mechanical misalignment can, of course, be calibrated out at the system level.

4. PROGRAM

As the driver turns on the indicator switch, the microcontroller starts the program. The program reads the inclination angle from the accelerometer. Then checks whether the turn is completed or not, by reading the value stored in the 'Turn Completed' variable.

If the turn has been completed, then the indicator lamp stops, and the program stops.
If the turn is not completed, the indicator starts blinking.

Now, the program checks if the vehicle is turning or not, by reading the 'Turning' variable value.

If the vehicle is turning, but its angle of inclination is greater than 85°, then the system assumes that the turn has been completed, thus turning off the indicator lamp.

If the vehicle is not turning, but is inclined less than 75° then the system perceives that the vehicle is still turning, thereby keeping the indicator lamp on, it acts accordingly.

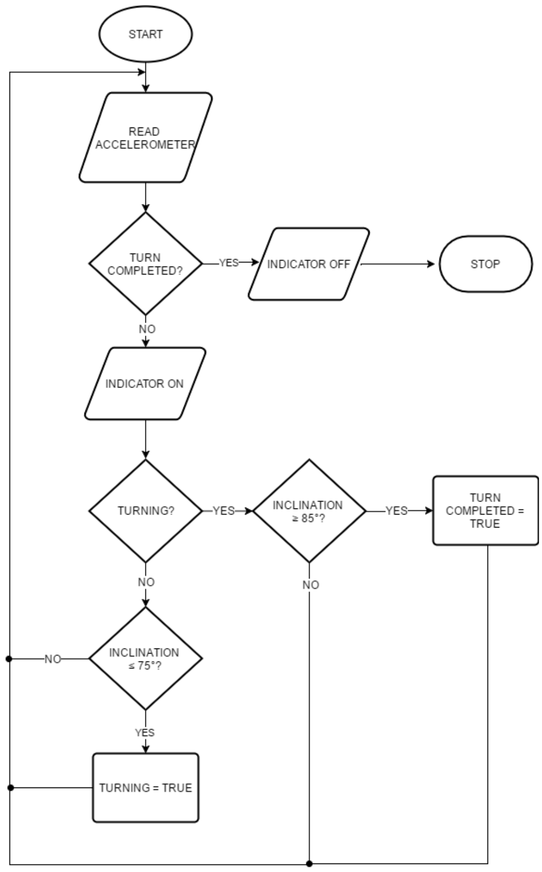

Figure 5 : Program Flow Chart

4.1 Validation of Apparatus or Code

The apparatus and the code have been thoroughly validated and verified. Several changes in the apparatus and the codes were made to overcome as much as limitations as possible.

Most of the mechanically vulnerable components were removed or altered accordingly. Earlier proposed idea to use servo mechanism for turning off the switch was replaced by digital switches. Microcontroller was changed from the expensive, and bulky Arduino Uno to a much more cost efficient ATmega 32.

Best efforts are made to make the code foolproof. Smoothing, averaging of the previous few values are considered to get a statistically stable system. Smoothing also reduces any misinterpretation that the system might read from road jerks, pit holes, etc. by decreasing the sensitivity of the accelerometer.

The current model gives a validation of over 90%. The remaining errors being caused by calibration problem, high sensitivity of the electrical instruments, and human errors.

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Availability Analysis of a Mechanical System with Load Sharing Arrangement Using Semi-Markov Approach

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A B S T R A C T

In this paper, an analytical approach based on Semi-Markov process has been proposed for availability assessment of a system with load-sharing arrangement. The current approaches are simulation based which takes more time. The model is developed by incorporating multi-level degradation at the component level. For a realistic analysis of mechanical systems, the time to failure of the components is modelled by a Weibull distribution and the time to repair is assumed as Lognormal distribution. The results of the proposed model have been compared with the results of a Markov model that is limited to exponential distribution.

Keywords—Semi-Markov, Markov, Weibull, lognormal, availability, steady state.

I. INTRODUCTION

Mechanical systems are employed in numerous applications such as power plant, aviation, manufacturing, air-conditioning, automotive, etc. These demand better performance for economic considerations and availability is the most desired requirement. Availability of a system is a combined effect of reliability and maintainability. It is a percentage of the system uptime. The availability analysis has gained immense attention of plant and maintenance engineers due to the development of increasingly complex industrial systems with higher cost. To maximize the utility of such systems, the time to repair (MTTR) should be minimized which increases the availability of the system [7]. The availability analysis also helps in optimizing the system maintenance and replacement policies in context of availability. Whenever a system breaks down due to the failure of any subsystem/component, its corrective maintenance is undertaken. Corrective maintenance is a task performed to identify, isolate, and rectify a fault so that the failed equipment, machine, or system can be restored to an operational condition within the tolerances or limits established for in-service operations. This increases the availability of the system. In the existing literature, several methods have been proposed to analyse the availability of a system based on Markov approach due to its relative simplicity and modest computational requirements.

A Markov model invariably assumes an exponential distribution for time to failure. However the failure rate of mechanical components is better represented by non- exponential distributions such as the Weibull distribution [1] thereby rendering the Markov approach inapplicable. Currently, simulation based approaches are used to handle non-exponential distributions. In this paper, an attempt has been made for analytical solution based on Semi-Markov process (SMP).

II. OVERVIEW OF SEMI-MARKOV PROCESS

A Semi-Markov process is essentially different from a Markov process in that it is "memory-less", i.e. while Markov processes are regenerative in each single moment, semi- Markov processes lose their memory only during the state transitions. The transition time between states can also be arbitrary random variables in SMP. Furthermore, in SMP, the amount of time spent in any of the states after entering it is a random variable described by a probability density function that depends not only on the state in which the process is in the considered moment, but also on the state that the system will change to at the next step.

Analytical Approach for SMP

The semi-Markov kernel which entirely describes the semi Markov process is described as follows:

$$Q_{i,j}(t) = \Pr\{X_{k+1} = j, T_{k+1} - T_k \leq t | X_0, \ldots, X_n; T_0, \ldots, T_n\}$$
$$= \Pr\{X_{k+1}=j, T_{k+1}-T_k \leq t | X_n\} = P_{i,j}.F_i(t)$$

Where:

- X_k demarcates the state after k transitions where the state k can take values ranging from 1 to n.
- $T_k - T_{k-1}$ is the time that is spent in the state k-1. This time depends upon the present state and the next state to which the transition takes place.
- P_{ij} is the transition probability from state i to state j and F(t) is the cumulative probability density function.

Semi-Markov models are more appropriate for mechanical systems since they are capable of handling non exponential distributions. The absence of exact methods for solving SMP models, however, makes it difficult to be treated analytically [4]. Some simulation-based softwares (such as RAPTOR, Block Sim) are widely used for the availability analysis of repairable systems, but the simulation based approaches are more time consuming than analytical approaches. Also, if the number of simulations performed is not large enough, the results are error-prone. At the same time, the increasing complexity of the SMP model with increasing number of components and/or increasing number of degradation and repair states limit the usage of analytical approaches.

This paper overcomes these limitations by firstly developing a model considering multi state degradation and then providing an analytical approach based on Semi Markov to evaluate the availability. The results have also been compared with a Markov model by approximating Weibull distribution to an exponential distribution [5]. Only the steady state availabilities have been evaluated, since the computation is difficult in case of time-dependent transition probabilities because of the convolution product of integrals.

The remaining paper is organized as follows: the two-stage analytical approach is presented for the steady-state availability analysis of SMP model, followed by a methodology for the same. Further, an example of a two- compressor load sharing system is illustrated and the last section concludes with the advantages, utility and the limitations of this method.

III. METHODOLOGY

A. Two-stage analytical approach

The proposed two-stage analytical approach involves the development of a Semi-Markov model for the system with corrective repair after identification of all the states. The state transition time distribution and appropriate parameters for failure time and repair time are identified. It is followed by the generation of the Semi-Markov Kernel characterising the SMP which deals with the evaluation of one-step transition probability matrix Z of the discrete time Markov chain of the SMP model. This one-step transition probability is used to compute the steady state probability of the state transitions of Semi-Markov chain which is followed by the calculation of mean sojourn time between any two transitions for each state. Steady state probability of each state is finally computed and summing the steady state probability values of all working states gives the availability measure

B. Methodology

Solution of the system model with the analytical semi- Markov approach involves the following steps:
Step 1
Construct a state diagram of the system displaying all the states of the system. The direction of arrow connecting the two states indicates the transition with the arrow showing the direction of transition.
Step 2
Select a proper system failure and repair distribution and their CDFs.
Step 3
Generate the Kernel matrix, Z for the system using the following element definition with t ®¥.

$$k_{ij}(t)=\begin{cases}0 & \text{:If there is no possible transition from State i within the transition time t.}\\ F_{ij}(t) & \text{:If there is a single possible transition from State i to State j within the transition time t.}\\ \int_0^t \bar{F}_{ik}\bar{F}_{im}\,dF_{ij}(x) & \text{:If there are multiple possible transitions from State I such as State j, State k and State m within transition time t.}\end{cases} \quad (1)$$

Steady state probability, v of all the Embedded Markov Chain (EMC) states is found using the equation.

$$\vec{v}=\vec{v}K(\infty),\quad \sum_1^n v_i=1,\ i\in\Omega \quad (2)$$

Step 4

Mean Sojourn time for all the states is evaluated using the following definition.

$$\tau_i=\begin{cases}\infty & \text{:If there is no possible transition from State i within the transition time t.}\\ \int_0^\infty \bar{F}_{ij}(t)dt & \text{:If there is a single possible transition from State i to State j within the transition time t.}\\ \int_0^\infty \bar{F}_{ij}\bar{F}_{ik}\bar{F}_{im}(t)dt & \text{:If there are multiple possible transitions from State I such as State j, State k and State m within transition time t.}\end{cases} \quad (3)$$

Step 5

Using the value of the steady state probabilities of the EMC and the mean sojourn time for the states, the steady state probability of the state P_i, for the SMP model is obtained using the following equation.

$$P_i=\frac{v_i\tau_i}{\sum_{j=1}^{n} v_j\tau_j},i\in\Omega \quad (4)$$

C. Illustrative Example

A two compressor load-sharing system is considered and its availability is determined using the two-stage analytical approach as presented in the paper. Multi-level degradation states have been considered for each compressor, along with perfect corrective repair. The time to failure and repair of the compressors are assumed to follow Weibull and lognormal distribution. The data for failure rate and repair rate is based on the data obtained from the literature [Barringer.com] The approach is demonstrated in a stepwise manner as follows:

a) SYSTEM DESCRIPTION

The system consists of two compressors connected in parallel sharing a load, even though each one of them is capable of carrying the full load alone. If one compressor fails, the other compressor takes up the entire load and its failure rate increases.

b) SYSTEM SMP MODEL

The system is modeled by considering four degraded states for each compressor (i.e. good as new, partially degraded, potentially degraded, and failed). Perfect repair is assumed for each component once it fails. Hence the total number of possible states is given by: $4^2=16$. The SMP model with these states is given by Fig. 1. Refer Table 1 in Appendix for the description of each state in the model.

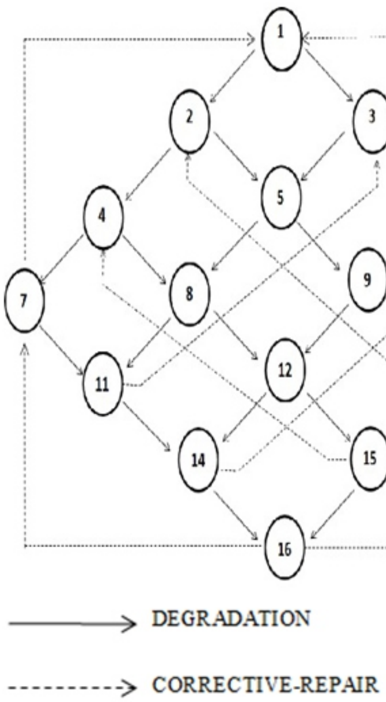

Fig. 1. Semi Markov model of two compressor load-sharing arrangement with multiple degradation states.

c) IDENTIFICATION OF FAILURE AND REPAIR TIME DISTRIBUTIONS AND THEIR PARAMETERS

d) TWO-STAGE ANALYTICAL TECHNIQUE FOR AVAILABILITY ASSESSMENT

Stage 1.

i. Developing Kernel matrix K(t)

The SMP model is characterized by its kernel matrix. Refer Fig. 2. for the kernel matrix of the model. Its elements are evaluated using Equation (1).

ii. Developing one-step transition probability matrix Z of EMC

The values of non-zero elements of this matrix are obtained when $t \rightarrow \infty$. MATLAB software has been used to evaluate the matrix elements.

iii. Evaluating steady-state probabilities of the state transitions of EMC

The various state transition probabilities of the states of EMC are obtained by solving the following equation:

$$[v_1\ v_2\ v_3\ v_4\ v_5\ v_6\ v_7\ v_8\ v_9\ v_{10}\ v_{11}\ v_{12}\ v_{13}\ v_{14}\ v_{15}\ v_{16}] = [v_1\ v_2\ v_3\ v_4 v_5\ v_6\ v_7\ v_8\ v_9\ v_{10}\ v_{11}\ v_{12}\ v_{13}\ v_{14}\ v_{15}\ v_{16}]*Z$$

The solution the above set of equations is obtained with the help of MATLAB. The obtained values are listed in Table I.

Stage 2.

iv. Calculating the mean sojourn time (holding time) of the states of SMP model

The stage 2 of the two-stage analytical approach deals with the determination of sojourn time of the states which are utilized to evaluate the steady state probabilities of the states of the system. The mean sojourn time, of each state is evaluated using Equation (3)

The evaluated sojourn time for the states of the SMP model is given in Table I

v. Steady state probabilities of states of the SMP model

The steady state probability, P_i of any state i for the SMP model is finally evaluated by using the Equation (4). For this evaluation, the values of v_i for each state and the corresponding value for sojourn time τ_i are obtained from Table I.

The evaluated values of P_i are listed in Table I.

e) AVAILABILITY MEASURE OF THE SYSTEM

The steady state availability of the system is evaluated by summing up the steady state probabilities of the working states of the SMP model, i.e.
$A = P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7 + P_8 + P_9 + P_{10} + P_{11} + P_{12} + P_{13} + P_{14} + P_{15}$

The value of steady state availability of the system using Semi-Markov process is found to be 0.99965 i.e. **99.96%**.

f) VALIDATION OF RESULTS BY MARKOV APPROACH

The results obtained from the proposed two-stage approach for solving SMP are compared with the results obtained by solving the same model with the conventional Markov approach.

The steps involved in obtaining the steady-state availability of the system using Markov approach can be summarized as:
(a) Equivalent component parameter values for Markov process

Since the failure and repair are represented by exponential distribution in Markov analysis, equivalent failure and repair rates need to be evaluated from Weibull parameter values for failure and log-normal parameter values for repair.

This is done by using the following two equations:

(i) $\lambda = 1/\{\theta * \Gamma(1+(1/\beta))\}$

where

λ –Equivalent Markov degradation parameter using gamma function (failure rate)

θ, β –corresponding Semi-Markov Weibull cdf parameters for degradation

(ii) $\upsilon = 1/(e^{u+0.5*\sigma^2})$

where
υ – Equivalent Markov repair parameter (repair rate)
σ, μ – corresponding Semi-Markov log-normal cdf parameters for degradation

(b) Formulate rate equation for each state of the system.

Rate equations are the first order ordinary differential equations representing the rate of change of probability of each state with time.

(c) Solve the differential equations simultaneously

The steady state probability values of the system using Markov analysis are given in Table III. The availability of the system is obtained by summing up the probabilities of the non-failed states of the system, and is given by the equation:

$$A = P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7 + P_8 + P_9 + P_{10} + P_{11} + P_{12} + P_{13} + P_{14} + P_{15}$$

The value of the steady state availability of the system using Markov process is found to be 0.9976 i.e. **99.76%**.\

IV. RESULTS

A comparison of the values of steady-state probabilities of the various system states obtained by employing Markov and semi-Markov approaches are given in Table III. The steady state availability of the system has been estimated to be 0.99965 by the Semi-Markov Process, while the Markov process predicts it to be 0.9976.

The results of the proposed model for solving SMP analytically have been found to be in close agreement with the Markov results. This validates the proposed analytical approach and also underlines its effectiveness in dealing with mechanical systems whose failure rate is not constant but increases with 'aging'.

V. DISCUSSION

The inability of the Markov process to handle non-exponential distributions necessitated the use of semi-Markov models for mechanical systems. In mechanical systems, the failure rate increases with age such that the failure is better represented by Weibull distribution. The proposed analytical approach requires lesser computational time as compared to simulation based approaches. Although the approach is demonstrated for a two component load sharing arrangement, it can also be extended to more complex systems. Since the closed form solutions are obtained, results are more accurate than obtained with simulation methods. Further, results are obtained in a single iteration unlike the large number of runs required in simulation. However, the proposed approach does have some limitations. The approach is applicable only for steady-state solutions and cannot be applied for transient analysis. At times, because of the non-exponential distributions, the integrals involved are difficult to solve and therefore, the availability cannot be determined. As the number of degradation states increases beyond four, the state model explodes into state space and becomes difficult to handle. Also, the data required for modeling the systems is not easily available given the high cost of equipment required for conditional monitoring and their limited availability.

VI. CONCLUSION

A Semi-Markov process model for a mechanical system incorporating multi-level degradation at the component level was developed. Weibull and Lognormal distributions, which are more appropriate for mechanical systems were considered. The analytical closed form solutions for availability assessment of mechanical system were presented. The results of the proposed model were compared with the results of a Markov model. The results obtained from the proposed model were found to be in close agreement with the Markov model. The suggested approach provides a realistic assessment of availability values of the repairable mechanical system. The approach is useful for designers in designing a system with high availability. The approach is also helpful for maintenance engineers in optimizing the system maintenance and replacement policies in the context of availability. This work can be extended to perform the transient analysis of the systems.

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APPENDIX

$$
K(t) = \begin{bmatrix}
0 & K_{1-2} & K_{1-3} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & K_{2-4} & K_{2-5} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & K_{3-5} & K_{3-6} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & K_{4-7} & K_{4-8} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & K_{5-8} & K_{5-9} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & K_{6-9} & K_{6-10} & 0 & 0 & 0 & 0 & 0 & 0 \\
K_{7-1} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & K_{7-11} & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & K_{8-11} & K_{8-12} & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & K_{9-12} & K_{9-13} & 0 & 0 & 0 \\
K_{10-1} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & K_{10-13} & 0 & 0 & 0 \\
0 & 0 & K_{11-3} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & K_{11-14} & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & K_{12-14} & K_{12-15} & 0 \\
0 & K_{13-2} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & K_{13-15} & 0 \\
0 & 0 & 0 & 0 & 0 & K_{14-6} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & K_{14-16} \\
0 & 0 & 0 & K_{15-4} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & K_{15-16} \\
0 & 0 & 0 & 0 & 0 & 0 & K_{16-7} & 0 & 0 & K_{16-10} & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
$$

Fig. 2. Kernel matrix Z of the SMP model

TABLE I
DESCRIPTION OF STATES, MEAN SOJOURN TIMES, STEADY STATE PROBABILITIES OF THE STATES OF EMC AND STEADY STATE PROBABILITIES OF THE STATES OF SMP MODEL

STATE	COMPONENT DESCRIPTION		SOJOURN TIME FOR THE STATE (HOURS)	STEADY STATE PROBABLITY OF STATE TRANSITION (v)	STEADY STATE PROBABLITY FOR THE STATE (P_i)
	COMPRESSOR I	COMPRESSOR II			
1	Good	Good	6265.8	0.159247068141239	0.308857529522570
2	Partially degraded	Good	5205.4	0.138270864361821	0.222789646803513
3	Good	Partially degraded	4350.9	0.100385627307617	0.135195071078425
4	Potentially degraded	Good	2564.6	0.104684696645310	0.08310230240024
5	Partially degraded	Partially degraded	4191.7	0.072747765690842	0.094388714523636
6	Good	Potentially degraded	1721	0.070921815516952	0.037780781261012
7	Failed	Good	722.84	0.096432662467288	0.021576279253125
8	Potentially degraded	Partially degraded	2488.7	0.039411976930899	0.030360644545285
9	Partially degraded	Potentially degraded	1751.4	0.048188664105315	0.026124046720021
10	Good	Failed	707.72	0.065574310626974	0.014364993108475
11	Failed	Partially degraded	720.263	0.035130827838397	0.007832307124952
12	Potentially degraded	Potentially degraded	1638	0.009181719033535	0.004655304744088
13	Partially degraded	Failed	713.93	0.047203535177761	0.010429885498486
14	Failed	Potentially degraded	670.4426	0.002706704292670	0.000561710617282
15	Potentially degraded	Failed	702.2398	0.007502889525551	0.001630888277721
16	Failed	Failed	467.3	0.002408872337828	0.000348433405002

TABLE III
COMPARISON OF STEADY STATE PROBABILITIES OF THE STATES OBTAINED FROM MARKOV AND SEMI -MARKOV MODEL

STATE	STEADY STATE PROBABLITY USING SEMI -MARKOV ANALYSIS	STEADY STATE PROBABILITY USING MARKOV ANALYSIS
1	0.3089	0.2778
2	0.2228	0.1924
3	0.1352	0.1416
4	0.0831	0.0833
5	0.0944	0.0960
6	0.0378	0.0475
7	0.0216	0.0208
8	0.0304	0.0414
9	0.0261	0.0324
10	0.0144	0.0189
11	0.0078	0.0106
12	0.0047	0.0139
13	0.0104	0.0129
14	0.0006	0.0036
15	0.0016	0.0046
16	0.0003	0.0024

CFD Analysis of Single Phase Turbulent Flow with Forced Convection Heat Transfer Inside a Circular Micro-Channel

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ABSTRACT

For many years, several experiments have been conducted to analyze the fluid flow and heat transfer parameters in microchannel heat sinks which are designed for applications in electronic cooling. these micro-channels provide high surface area per unit volume and large potential for heat transfer. This paper addresses and investigates the study of a single phase water cooled circular micro-channel heat sink with CFD. The hydrodynamic and thermal behavior of the system has been studied in terms of velocity, pressure and temperature contours. Simulations have been done for microchannel of diameter .76mm with water as coolant. The results have been compared with the results of other researchers.

Keywords- Micro-channel; CFD; Forced Convection.

Notation-

A	Area of cross- section	q''	Heat flux
C_P	Specific heat	G_k	Generation of turbulence K.E due to mean velocity gradient
D_h	Hydraulic diameter	G_b	Generation of turbulence K.E due to buoyancy
f	Friction factor	Y_m	Fluctuating dilation in compressible turbulence to overall dissipation rate
k	Thermal conductivity	$C1\xi$	1.44
V	Velocity	$C2\xi$	1.92
µ	Viscosity	σ_k	Turbulent Prandtl number for k
ρ	Density	σ_Γ	Turbulent Prandtl number for ξ
S_k	User defined source term	S_ξ	User defined source term
P	Perimeter	h	Convective heat transfer coefficient
k	Thermal conductivity	L	Characteristic length

1. INTRODUCTION

1.1 Microchannel Heat Sink

With advancement of microelectronics heat removal becomes of great importance. This is due to integrated density of chips and increased current and voltage handling capacity of these devices. The heat removing capacity of microchannel is 50 times higher than conventional heat sinks. These microchannel induce thermal stresses on the system which are being cooled. In order to avoid these thermal stresses large pressure drop is required which further needs a pumping system. Several improvements have taken in the field of microchannel. One of such example is multilayered microchannel. The main advantage of multilayered microchannel is that it needs less pressure drop across the microchannel and it offers less thermal resistance as well. Obot in 2003 gave a simpler classification which is based on hydraulic diameter. According to his classification channel whose hydraulic diameter is less than 1mm is called microchannel. Hydraulic diameter can be defined as

$$D_h = 4A \div P \quad (1)$$

Micro-channels provide one of the alternatives to finned tube heat exchanger. Microchannel heat sinks are usually made of material of high thermal conductivity such as copper and silicon using precision machining of micro machining processes. Microchannel is actually composed of a number of parallel micro channels and coolant is forced through this microchannel. It is the coolant that takes away heat from the heated surface. Advantages of using microchannel are as follows:

- It provides large surface area to volume ratio.
- It facilitates a high value of convective heat transfer coefficient.
- It has small mass and volume.
- It requires less inventory.
- Because of these merits micro-channels are well suited as heat sink for devices like high performance micro-processors, laser diode array, radars and high energy laser mirrors.

2. MATHEMATICAL FORMULATION

2.1 Introduction

A two dimensional analysis of single phase flow and heat transfer has been carried in a circular microchannel of diameter 0.76 mm and of length 152.4 mm. Initial length of 63.5 mm which is insulated, precedes the heated section. This ensures that the flow is fully developed before entering the heated region. The heated length of microchannel is subjected to uniform heat flux intensity of 3000 W/m^2. After the heated region insulated micro-channel of length 152.4 mm follows. Distilled water has been used as the coolant which is entering inlet of the microchannel with velocity of u = 18 m/s. the operating pressure is 1 atm in absolute scale. A schematic diagram of the problem has been shown in the figure below:

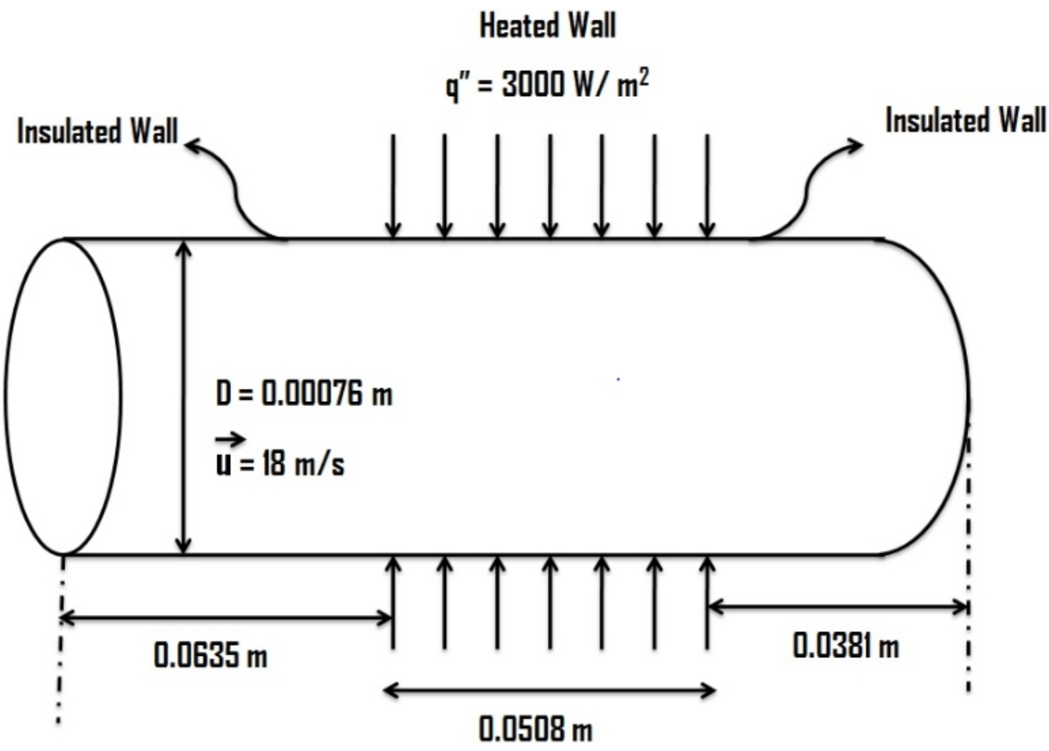

Figure 1. Fluid flow through a circular micro channel

2.2 Assumptions

- Steady state heat conduction.
- No heat generation within the microchannel.
- Uniform heat transfer coefficient over the entire surface of the microchannel.
- Homogeneous and isotropic microchannel material (i.e. thermal conductivity of material constant).
- Negligible contact thermal resistance.
- Heat conduction one-dimensional.
- Negligible radiation
- Thickness of microchannel is negligible and is placed horizontally.
- Density of the coolant is constant.

2.3 CFD Modelling- Governing Equations

In axis symmetric geometry continuity equation gets transformed as

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho v_x) + \frac{\partial}{\partial r}(\rho v_r) + \frac{\rho v_r}{r} = 0 \quad (2)$$

Where, x is axial direction while r is radial direction.

In case of 2D axis symmetric problem the momentum conservation equation in axial and radial direction is given as below:

$$\frac{\partial}{\partial t}(\rho v_x) + \frac{1}{r}\frac{\partial}{\partial x}(r\rho v_x v_x) + \frac{1}{r}\frac{\partial}{\partial r}(r\rho v_x v_r) = -\frac{\partial p}{\partial x} + \frac{1}{r}\frac{\partial}{\partial x}\left[r\mu\left(2\frac{\partial v_x}{\partial x} - \frac{2}{3}(\nabla.\vec{v})\right)\right] + \frac{1}{r}\frac{\partial}{\partial r}\left[r\mu\left(\frac{\partial v_x}{\partial r} + \frac{\partial v_r}{\partial v_x}\right)\right] + F_x$$

(3)

$$\frac{\partial}{\partial t}(\rho v_r) + \frac{1}{r}\frac{\partial}{\partial x}(r v_x v_r) + \frac{1}{r}\frac{\partial}{\partial r}(r v_r v_r) = -\frac{\partial p}{\partial r} + \frac{1}{r}\frac{\partial}{\partial x}\left[r\mu\left(\frac{\partial v_r}{\partial x} + \frac{\partial v_x}{\partial r}\right)\right] + \frac{1}{r}\frac{\partial}{\partial r}\left[r\mu\left(2\frac{\partial v_r}{\partial r} - \frac{2}{3}(\nabla.\vec{v})\right)\right] - 2\mu\frac{v_r}{r^2} + \frac{2}{3}\frac{\mu}{r}(\nabla.\vec{v}) + \rho\frac{v_z^2}{r} + F_r$$

(4)

Where

$$\nabla.\vec{v} = \frac{\partial v_x}{\partial x} + \frac{\partial v_r}{\partial r} + \frac{v_r}{r}$$

(5)

Since the microchannel thickness is small and it is horizontally placed, body forces F_x and F_r is taken to be zero. This will modify eqn. 2 and eqn. 3 as below:

$$\frac{\partial}{\partial t}(\rho v_x) + \frac{1}{r}\frac{\partial}{\partial x}(r\rho v_x v_x) + \frac{1}{r}\frac{\partial}{\partial r}(r\rho v_x v_r) = -\frac{\partial p}{\partial x} + \frac{1}{r}\frac{\partial}{\partial x}\left[r\mu\left(2\frac{\partial v_x}{\partial x} - \frac{2}{3}(\nabla.\vec{v})\right)\right] + \frac{1}{r}\frac{\partial}{\partial r}\left[r\mu\left(\frac{\partial v_x}{\partial r} + \frac{\partial v_r}{\partial v_x}\right)\right]$$

(6)

$$\frac{\partial}{\partial t}(\rho v_r) + \frac{1}{r}\frac{\partial}{\partial x}(r v_x v_r) + \frac{1}{r}\frac{\partial}{\partial r}(r v_r v_r) = -\frac{\partial p}{\partial r} + \frac{1}{r}\frac{\partial}{\partial x}\left[r\mu\left(\frac{\partial v_r}{\partial x} + \frac{\partial v_x}{\partial r}\right)\right] + \frac{1}{r}\frac{\partial}{\partial r}\left[r\mu\left(2\frac{\partial v_r}{\partial r} - \frac{2}{3}(\nabla.\vec{v})\right)\right] - 2\mu\frac{v_r}{r^2} + \frac{2}{3}\frac{\mu}{r}(\nabla.\vec{v}) + \rho\frac{v_z^2}{r}$$

(7)

In the present problem standard k-ε model has been selected as the flow is turbulent. Transport equations that are used by ANSYS for single phase turbulent flow are as follows:

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k v_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k + G_b - \rho\varepsilon - Y_M + S_k \quad (8)$$

$$\frac{\partial}{\partial t}(\rho \varepsilon) + \frac{\partial}{\partial x_i}(\rho v_i \varepsilon) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + C_{1\xi}\frac{\varepsilon}{k}(G_k + C_{3s}G_b) - C_{2s}\rho\frac{\varepsilon^2}{k} + S_\xi \quad (9)$$

2.4 Geometry in ANSYS Workbench

As per our problem specification cross-section of microchannel is circular and heat flux is uniform, the flow is assumed to be axis symmetric. When we opt for axis symmetric Cartesian coordinates gets converted into cylindrical polar coordinates. It implies that flow parameters vary in axial direction corresponding to x coordinate and radial direction corresponding to y coordinates in 2-D geometry. The properties are assumed to be independent of azimuthal coordinate θ. Therefore, the above problem microchannel can be modeled in rectangular domain.

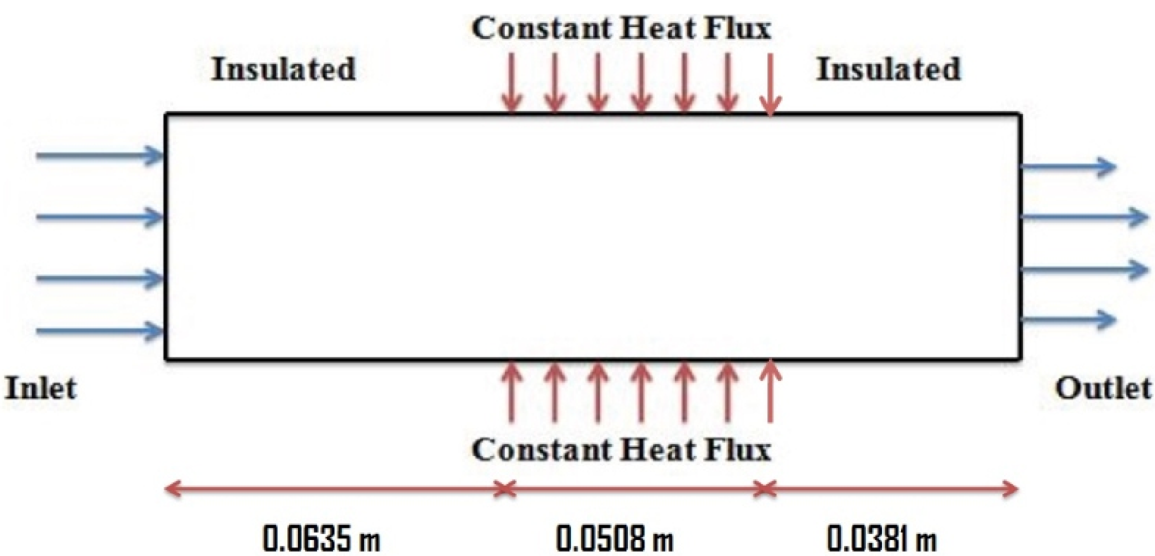

Figure 2. Schematic diagram of circular microchannel as per problem specification

2.5 Physical Setup

- Double precision solver
- Cylindrical coordinate system
- Pressure based solver
- Steady state
- Energy equation model(k-ξ)
- Enhanced wall treatment for near wall treatment
- Fluid material- water
- Material for microchannel – copper
- Boundary conditions: operating pressure=101325 Pa; heated wall q"=3000W/m^2; other than heat wall q"=0;
- Boundary condition at inlet: velocity type; axial velocity= 18m/s; turbulent viscosity=10; % intensity of turbulence=5
- Boundary condition at inlet: P_{gauge}=0; % of backflow turbulent intensity=5; backflow turbulent viscosity ratio=10

2.6 Numerical Solutions

Governing equations that FLUENT uses to solve the problem are non-linear equations which are solved in a no of iterations**.** Following are the salient features of the solution**:**

- Discretization scheme: 2^{nd} Order Upwind
- Solution initialization: Standard
- Convergence criteria: 10^{-6}
- No of iterations :1000
- Iterations required for convergence :316
- Solution initialization: Standard

In order to analyze skin friction coefficient other than standard quantities, skin friction coefficient is transferred to post-processor from additional quantities'

3. RESULTS AND DISCUSSIONS

3.1 Introduction

A 2-D model was developed to study and analyze the fluid flow and heat transfer in the circular channel. A number of calculations are performed by FLUENT and results are produced to show the variation of different parameters.

3.2 Simulation of Circular Microchannel

3.2.1 Velocity Vector

For velocity vector location is selected as periodic 1. This facilitates the display of velocity vector periodically along the entire surface of geometry. Line arrow is selected as symbol and symbol size is selected as 0.1. ANSYS 14.5 displays only half of the cross section thereby showing velocity vector and other variation of half of the cross section only. In view tab, mirroring condition is applied about ZX plane in default transform to work out this problem. In order to have a better view of the result, scale is applied and set as (1, 30, 1). This stretches the result in Y direction by 30. After all these settings, velocity vector appears as below:

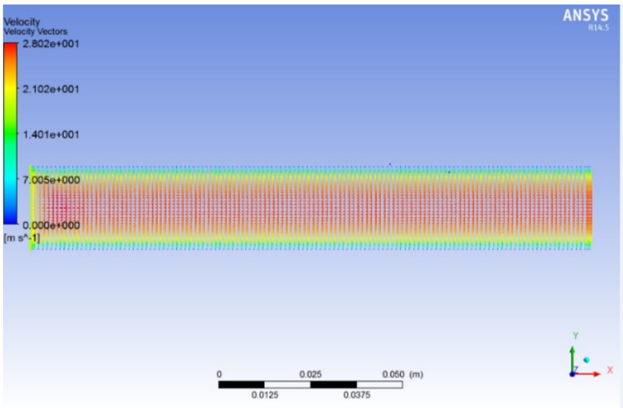

Figure 3. Velocity vector

3.2.2 Velocity Contour

For plotting velocity contour, first of all we open the contour tab and in geometry tab periodic 1 is selected as location. Velocity is set as variable and again for viewing option reflection or mirroring is selected. Method of mirroring is selected as z-x plane and again we apply scale in order to have better view of result which is set as (1, 30, 1). This stretches our result in y direction. After all these settings our velocity contour appears as below:

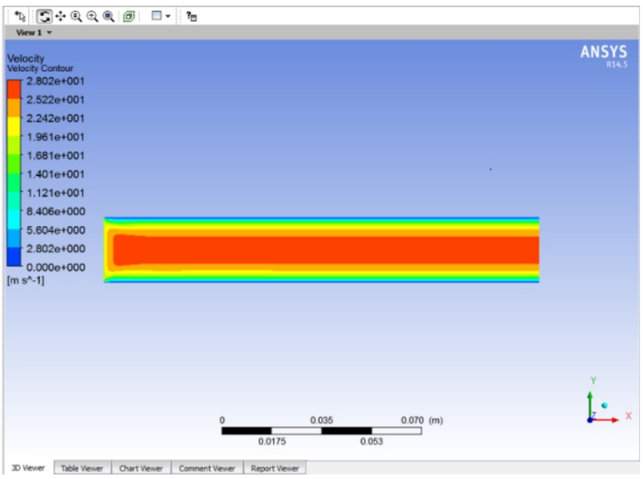

Figure 4. Velocity contour

The minimum value of velocity is zero which is near the wall of the channel which is in no slip condition and the maximum value of velocity is 28.0201 m/s which is in the central region near the axis of the channel.

3.2.3 Temperature Contour

For the temperature contour we follow the same procedure as that of previous case except temperature is selected as the variable which appears as below:

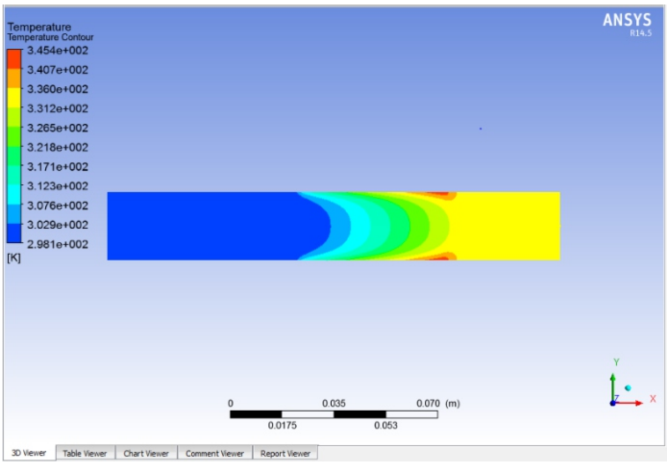

Figure 5. Temperature Contour

The minimum value of temperature is 298.15 K which is at the inlet of the channel. While the maximum value of temperature is 345.404 K which is near the wall and at end of the heated region of microchannel.

3.2.4 Pressure Contour

Pressure is set as variable while all process remains the same. Pressure contour appears as below:

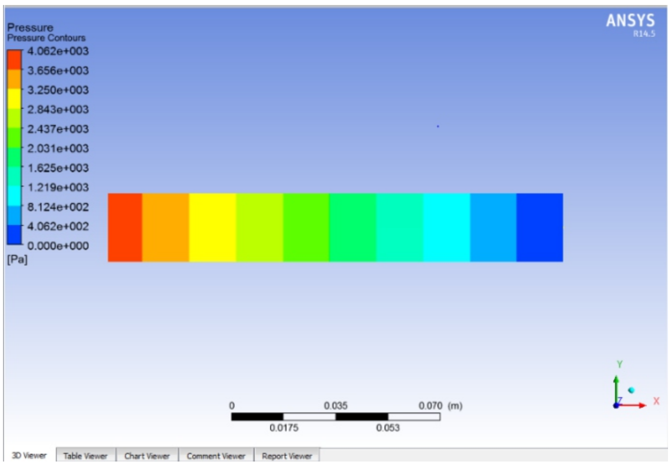

Figure 6. Pressure contour

The maximum value of gauze pressure is 4062.1 Pa which is at the inlet of the channel while the minimum value of gauge pressure is 0 Pa which is at the outlet of the channel as our operating condition is atmospheric pressure. As per the prediction, pressure decreases in the direction of flow.

3.2.5 Wall Temperature Variation

Again for this purpose we need to create another separate line. Under location tab we select line and name it as walls and two-point method is selected as method for drawing line. The two point for line named wall is specified as point1 (0, 0.00038, 0) and point2 as (0.1524, 0.00038, 0). No of samples is selected as 100. On applying these data line named outlet is created. Now for plotting wall temperature variation under data series tab, wall is selected as location, temperature is selected as variable under X axis tab and temperature is selected as variable under Y axis tab. Graph of wall temperature appears as below:

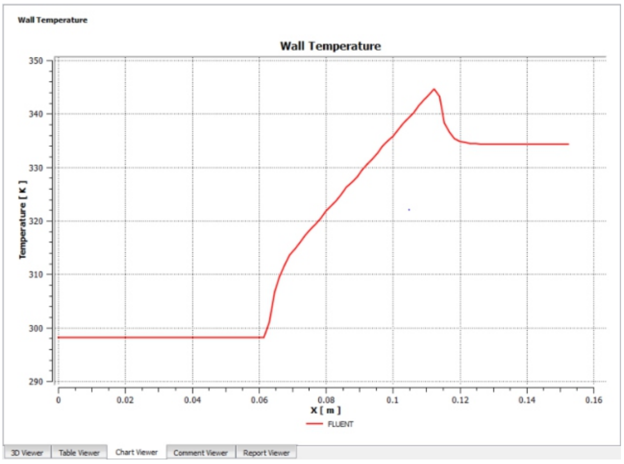

Figure 7. Wall temperature variation

3.2.6 Pressure Plot along Centerline

As centerline is already created we just need to specify centerline as location and X as variable for x axis tab and pressure as variable for Y axis tab. With all these data the variation of pressure along centerline is plotted which appears as below:

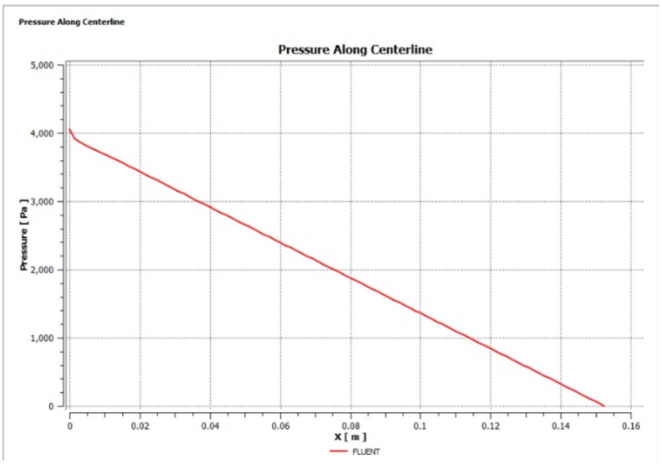

Figure 8. Pressure along centerline

3.2.7 Temperature Profiles

In this section we are going to plot the variation in temperature at the three different locations for which lines have already been created in the previous section at x= 0.0635m, x=0.1143m and x= 0.1542m. All processes are same as that of the previous case except for the fact that in this case temperature is selected as variable under X axis tab while Y is selected as variable under Y axis tab. The temperature profiles appear as below:

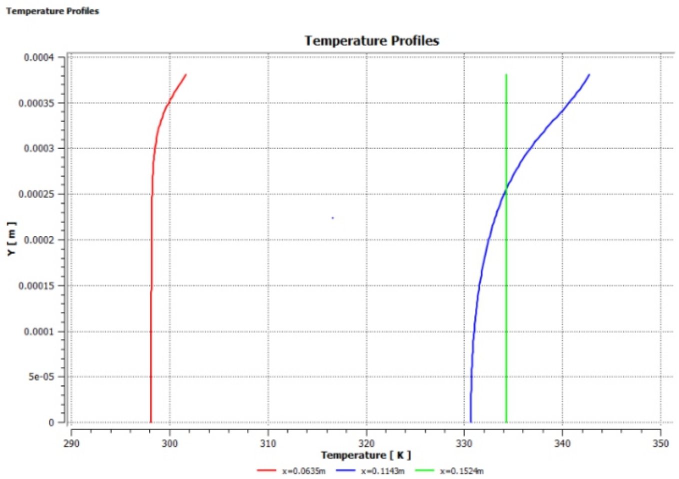

Figure 9. Temperature profiles at x= 0.0635m, x=0.1143m and x= 0.1542m

It is obvious from the graph that as we move closer to the wall of channel temperature increases and temperature is constant at the exit of channel which complies with the graph drawn earlier under the heading "graph of temperature along outlet". At the beginning of the cross section where heating starts increase in temperature is less while at the cross section where heating region ends increase in temperature is more which is obvious.

3.2.8 Wall Shear

The line named wall has already been created. So under data series tab wall is specified as the location. X is selected as variable for X axis tab while Wall Shear is selected as variable under Y axis tab. When above said conditions are applied the variation of wall shear is obtained as below:

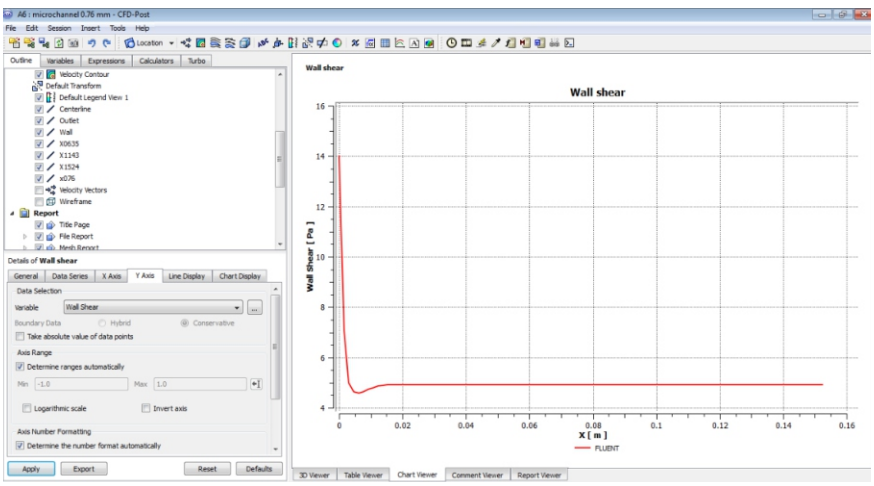

Figure 10. Wall shear variation

3.3 Model Validation

3.3.1 Grid Independence Test

The model is tested for grid-independence to give proper resolution to the region where large gradients of fluid flow and heat transfer characteristic is predicted. A grid independence test was carried out by increasing the number of nodes and cells and decreasing the element size for the microchannel heat sink which is given in table below:

Table 1. Grid Independence Test

Model	Model 1	Model 2
Nodes	5549	71053
Element Size	8.82e^-4	8.82e^-5
Cells	5340	69280
Faces	10888	140332
Minimum Orthogonal Quality	1.0000e^00	9.74315e^-1
Maximum Aspect Ratio	2.75982e^22	3.69106e^1

The fine grid mesh for the x and y-directions is adopted to properly resolve the velocity and viscous shear layers and to more accurately define the heat transfer at the surface of the channel, thereby improving the temperature resolution. CPU time as well as the memory storage required increases dramatically as the number of grid nodes is increased. However, results and graphs obtained upon refining the mesh is approximately similar and very close to the previous results which confirm the grid independence of the present simulation.

3.3.2 Model Validation with Previous Experimental Studies

Nusselt Number Calculation

Nusselt number is a non-dimensional number which provides us information regarding convective heat transfer. Expression for convective heat transfer at the channel wall is give as below:

$$q''_w = h(T_w - T_m)$$

(10)

From the above expression convective heat transfer coefficient is found as below:

$$h = \frac{q''_w}{(T_w - T_m)}$$

(11)

When we put the value of convective heat transfer in the expression of Nusselt number expression changes as below:

$$Nu = \frac{hL}{k} = \frac{q''_w(2R)}{k(T_w - T_m)}$$

(12)

Where

h is the convective heat transfer coefficient.

k is thermal conductivity of water.

L is the characteristic length. For the circular channel it is the diameter of the channel.

q''_w is the heat flux to which heated wall of microchannel has been subjected.

T_w is the temperature of channel wall at a given location.

T_m is mean temperature in the channel at the same location where Tw has been defined.

Validation of CFD Modeling

The present CFD model is validated by comparing the value of Nusselt number calculated by post processor of FLUENT to the value of Nusselt number that is obtained from the correlations for the microchannel by T. M. ADAMS. In the experimental investigation conducted by T. M. ADAMS found that the value of Nu that is determined experimentally comes out to be much higher than the value that is calculated using conventional correlations. Gnielinski modified correlation given by Petukhov which is given as below:

$$Nu = \frac{\left(\frac{f}{8}\right)(Re - 1000)Pr}{1 + 12.7\left(\frac{f}{8}\right)^{\frac{1}{2}}\left(Pr^{\frac{2}{3}} - 1\right)}$$

(13)

Nu is Nusselt number

Re is Reynolds number

Pr is Prandtl number

F is friction factor whose expression was given by Gnielinski as below:

$$\mathbf{f = (1.82\ log(Re)-1.64)^{-2}} \quad \textbf{(14)}$$

Nu value calculated by Gnielinski eqn. comes to be 135.50. T. A. ADAMS modified Gnielinski eqn. which is as below:

$$\mathbf{Nu = Nu_{Gn}\ (1+ F)} \quad \textbf{(15)}$$

Where F is given by

$$\mathbf{F = C.\ Re.\ (1- (D/D_o)^2)} \quad \textbf{(16)}$$

Where

$C = 7.6 \times 10^{-5}$ and $D_o = 1.164$ mm

4. CONCLUSION

Result of CFD analysis was validated using results of experimental work of T. A. ADAMS and therefore the model is genuine and can be applied to any fluid flow and heat transfer problem in the circular microchannel. Features of this chapter can be concluded as below:

Simulation of circular microchannel, of diameter 0.76mm with water as a coolant with turbulent flow and forced convective heat transfer subjected to uniform heat flux of 3000 W/m^2, was performed.

Simulation of microchannel of diameter 0.76mm with air as a coolant was also performed.

Graphs comparing axial velocity at three different locations namely at x = 0.0635m, x = 0.1143m, x = 0.1542m inside the channel, were plotted. The axial velocity variations in Y direction, in case with water as a coolant overlapped each other but in case of air the variation in axial velocity at different locations were different.

The maximum temperature attained by the coolant in case of air was 346.399 K while in case of water it was 345.404 K. This is due to fact that water has higher specific heat capacity and thereby more heat carrying capacity.

Variation in wall shear was plotted in the direction of flow. The plot showing variation in wall shear first fell and then rose a little bit in the region where flow is not fully developed when using water as a coolant. But in case of air as a coolant curve first falls down in the flow developing region, remains constant once flow is fully developed, rises in the heated region after which it again remains constant.

Rise in temperature of channel wall is more in case of air when used as a coolant.

Deviation in value of Nusselt number calculated experimentally, from the values which are predicted from different correlations are more for higher Reynolds number.

The present analysis shows that water promises to be a better coolant when compared to air.

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