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Recent Trends in Thermal and Fluid Sciences

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Preface

The field of mechanical is considered to be an evergreen branch that has served the humankind from the time immemorial and still remains a reckoning harbinger of change that encompass various fields, namely power production, manufacturing, thermal engineering, design, defence, aerospace, biomechanics, product developments, and others. With this backdrop, an International Conference on Mechanical Engineering (INCOME-2023) was organized by Netaji Subhas University of Technology, New Delhi, India, on 1 and 2 September 2023. This conference was aimed at providing a platform to the researchers and engineers to share and discuss various aspects of mechanical engineering and its applications. The conference provided an excellent opportunity for the presentation of new inventions, discoveries, implementations, improvements, product innovations, and manufacturing techniques. The conference was a right place for the exchange of new ideas and transfer of knowledge. The INCOME-2023 was a good platform for interaction between industry and academic professionals as well. The conference was held in mixed mode. A large number of papers were presented at the conference venue, and a few papers were presented online. An effort has been made to publish some of the selected peer-reviewed research papers on recent trends in thermal and fluid sciences which has culminated into this edited book.

About ninety research papers were presented during two days conference. The researchers from industry and academics shared the most recent studies, held discussions, and exchanged ideas on several practical topics. The conference provided an opportunity for collaboration among academicians and practitioners. The recent developments and innovations in various fields of mechanical engineering were also shared through keynote lectures. The book covers the thermal and fluid topics in mechanical engineering areas such as combustion and biofuels, heat and mass transfer, refrigeration and air-conditioning, fluid–structure interaction, flow control, aerodynamic, aero acoustics, turbulence and instabilities, rheology and complex fluids, turbo machinery, and thermodynamics. This book connects together various topics of thermal and fluid sciences and will be beneficial for industry as well as for academic professionals working in this field.

The editors acknowledge all the authors for their contribution to this volume. We sincerely express our profound gratitude to the candid support extended by Netaji Subhas University of Technology, New Delhi. The editors also thank faculty and staff of the department of mechanical engineering for their enthusiastic support to accomplish this goal. We would also like to thank all those who directly or indirectly assisted us in this work. Last but not the least, we are grateful to the publishers of this book for publishing the selected proceedings of INCOME-2023. The editors welcome the readers' suggestions for improvement in this book.

New Delhi, India	Achhaibar Singh
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October 2023	

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About the Editors

Dr. Achhaibar Singh is a visiting faculty at the Department of Mechanical Engineering, Netaji Subhas University of Technology, New Delhi, India. He obtained graduate degree in engineering from Madan Mohan Malaviya University of Technology Gorakhpur; postgraduate degree from Indian Institute of Technology Bombay; and Ph.D. from Indian Institute of Technology Bombay. He has worked 18 years in industry as an engineering manager and the R&D head. His areas of research are refrigeration and air-conditioning, rotating flows in turbo machines, and computational fluid dynamics. He has published seven research papers in the reputed peer-reviewed international journals and several papers in conferences. Currently, he is working in the areas of flow in rotor stator system and CFD of rotating flow using finite element method.

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Thermal

Design of Solar Panel Cleaning Robot

A. Venkatnikhil, Shama Ravichandran, and K. H. Naveen Kumar

1 Introduction

Solar cells use solar energy to produce electricity which can be used by electrical, commercial, and residential applications directly. This will generate electricity without affecting the environment and human health [1]. The generation of power by means of solar panel depends upon the amount of light received by the semiconductors. In modern world, significant progress in the use of alternative or renewable energy sources, including solar energy, is already visible [2]. Experiments reported that a layer of 4 gm dust per panel can reduce the power generation by 40% [3]. Currently, commercially available photovoltaic (PV) panels have an efficiency between 10 and 30% [4].

Different factors like clouding, wind, and soiling affect the production of electricity. Soiling is one of the major factors that affect the efficiency of electricity production due to the accumulation of dust on the surface of the solar panel, which in turn blocks the sun rays from reaching the panel [5]. To overcome these challenges and to increase the efficiency of the solar panel, regular cleaning of the solar panel is mandatory. Cleaning solar panels with water during high temperatures can reduce the panel temperature and can also increase the life of the solar panel [6]. From literature, it can be concluded that cleaning done using cold water caused the panel temperature to drop to a maximum temperature of 40 °C, which led to an increase in the efficiency of solar cells by 12% [7]. This shows that the efficiency of the solar panel increases when there is a reduction in panel temperature. Heat sinks can also be used as a cooling technique which results in efficiency improvement up to 32%.

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Another way to improve the efficiency is by using an anti-reflection coated solar panel [8, 9]. Recently numerous efforts have been made to improve the efficiency of the solar panel so that it results in higher economic productivity [10]. High efficiency can also be achieved using solar tracking techniques. Solar tracking can be either single axis or dual axis, as long as it satisfies the economic requirements and results in high efficiency [11–13].

Different methods for cleaning the solar panel are available in literature [14]. First method involves cleaning solar panels manually. In this method, human beings will clean the solar panel using brush and water. Even though this method is simple, it is proven to be expensive and labour-intensive in large-scale solar panels installations [15]. To overcome the disadvantage of this method, automatic or robot cleaners were introduced. These types of systems will perform well, with less or no human interaction [16].

In this paper, three design concepts for a low-cost solar panel cleaning robot are presented. This paper is demonstrated as follows: Firstly, an introduction on solar panels and existing cleaning methods available for solar panels are shown in Sect. 1. Three different cleaning robot design concepts and selection of one concept are presented in Sect. 2. Specifications of the robot are arrived in Sect. 3, and development of robot is shown in Sect. 4 followed by conclusion in Sect. 5.

2 Design Concepts

In this section, three different design concepts for the development of a solar panel cleaning robot are presented. The design concepts are developed using CATIA software. Based on the advantages and disadvantages of the design concepts, one optimal concept is selected for fabrication.

2.1 Design Concept 1 (Round Brush for Wet Cleaning)

Design concept 1 is shown in Fig. 1. In concept 1, a round brush is selected for performing the cleaning operation. A total of two round brushes are connected to individual motors which in turn is connected to Arduino using a motor driver for controlling the brushes. Separate high pressure water connection is provided for both the brushes which enables effective removal of dirt. The advantages of this design are: (1) Enhanced cleaning of the solar panel which is facilitated by means of separate motor connected brushes. (2) Easy removal of hard dirt. The disadvantages of this design are: (1) Some parts of the panel are left uncleaned due to the gaps between the two brushes. (2) Round brushes can cause minor damages to the panel when high rpm rotation occurs at a single place for extended time duration. (3) Consumes more power as two motors are used.

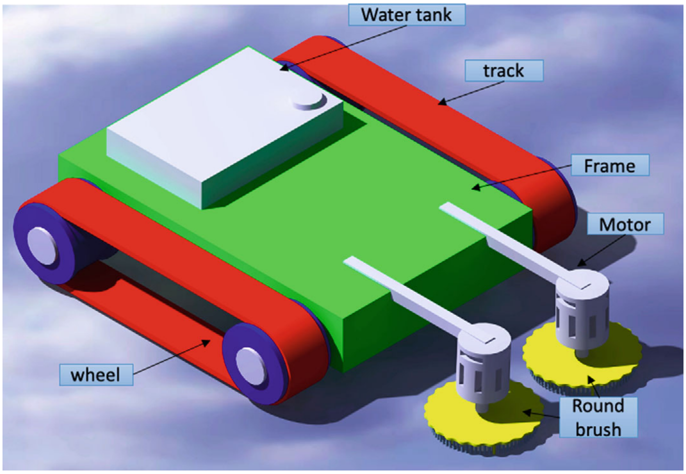


Fig. 1 Robot with round brush for wet cleaning

2.2 Design Concept 2 (Round Brush for Dry Cleaning)

Design concept 2 is shown in Fig. 2. Vacuum cleaning method is used here. In this concept, a total of two round brushes with individual motors are used for dry cleaning. Two brushes are placed at the front side of the robot, which aids in removal of dust and dirt. Removed dust and dirt will be gathered at the centre of the robot due to the rotation of brushes in opposite direction. The gathered dust at the centre of the solar panel will be sucked in through the pipes of the vacuum cleaner and stored in a dust tank. The advantages of the proposed design are given as follows: (1) Effective cleaning of the solar panel when the surface of the panel is dry. The disadvantages are: (1) Cannot be used when the surface of the solar panel is wet. (2) Difficult to clean heavy dirt accumulated in the absence of water.

2.3 Design Concept 3 (Roller Brush for Wet and Dry Cleaning)

Design concept 3 is shown in Fig. 3. In this concept, a long roller brush consisting of soft bristles is used. The brush is attached to a motor. This robot is designed to perform both wet and dry cleaning. The advantages of this design concept are: (1) Effective cleaning of the solar panel by means of roller brush. (2) Smooth cleaning without damaging the surface of the panel due to the usage of soft bristles. (3) Performs both wet and dry cleaning. (4) Power consumption is less compared to the previous two design concepts due to the usage of a single motor. Comparing the advantages and

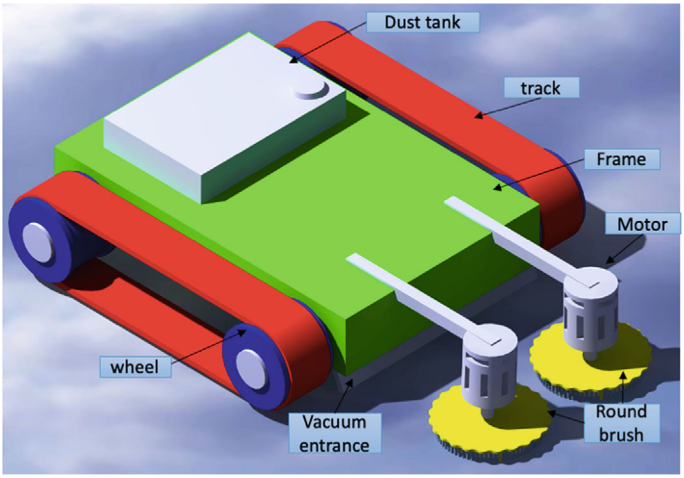


Fig. 2 Robot with round brush for dry cleaning

disadvantages of all the three design concepts, design concept 3 is selected as the optimal design for development.

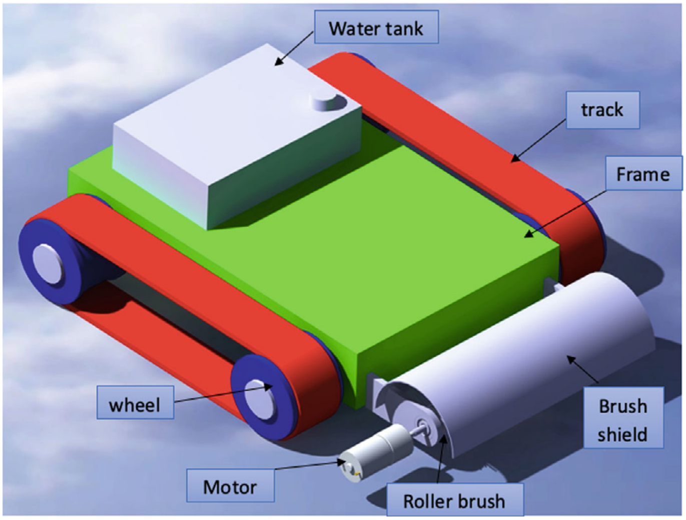


Fig. 3 Robot with roller brush for dry and wet cleaning

3 Specifications of the Robot

In this section, the specifications of the robot are explained in detail.

3.1 Centre of Gravity

Solar panels are usually situated at a height of 30 feet from the ground. The robot is designed to work at an inclination of 10° when placed on top of the solar panel. Hence, it is important to determine the centre of gravity (CG) of the robot. Four wheels are attached to the robot with rubber tracks. The mass of each wheel is 120 kg. CG of the robot is shown in Fig. 4.

Ground reaction of front wheels is shown in (1)

$$R_{\mathrm{f}} = M_{\mathrm{f}} \times g \tag{1}$$

Ground reaction of rear wheels is shown in (2)

$$R_{\mathrm{r}} = M_{\mathrm{r}} \times g \tag{2}$$

At longitudinal position, weight of the robot is shown in (3)

$$\mathrm{Wt} = \frac{M_{\mathrm{f}} \times L}{b} \tag{3}$$

CG at position b is shown in (4)

$$b = \frac{(m_1 + m_2) \times L}{m_1 + m_2 + m_3 + m_4} \tag{4}$$

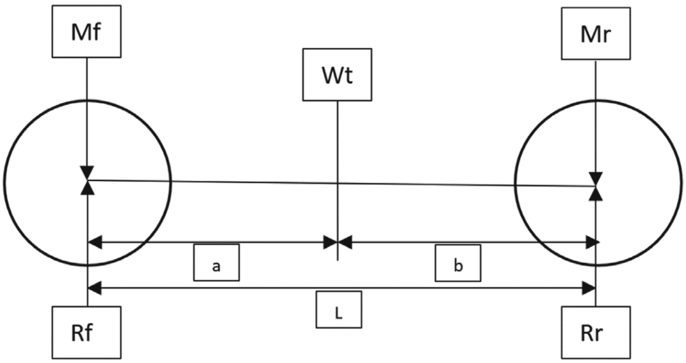


Fig. 4 Centre of gravity of robot

CG at the position a is shown in (5)

$$a = \frac{(m_1 + m_2) \times L}{m_1 + m_2 + m_3 + m_4} \tag{5}$$

CG at 10° inclination is shown in (6)

$$H = \frac{\frac{R_{\text{rea}} \times L}{\text{Wt}} - b}{\tan \alpha} \tag{6}$$

where R_{f} = ground reaction of front wheels in kg-mm, M_{f} = mass of front wheels in kg, R_{r} = ground reaction of rear wheels in kg-mm, M_{r} = mass of rear wheels in kg, Wt = weight in longitudinal position in kg, L = distance between front and rear wheel in m, m_1 = mass of front right wheel in kg, m_2 = mass of front left wheel in kg, m_3 = mass of rear right wheel in kg, m_4 = mass of rear left wheel in kg, α = inclination angle, and R_{rea} = average value of mass of both front and rear wheel. Based on the calculations, the specifications of the robot are arrived as follows: H = 9 mm, a = 200 mm, b = 200 mm, and wt = 0.48 kg.

3.2 Torque

Torque of the robot is shown in (7)

$$T = r \times F \times \sin(\theta) \tag{7}$$

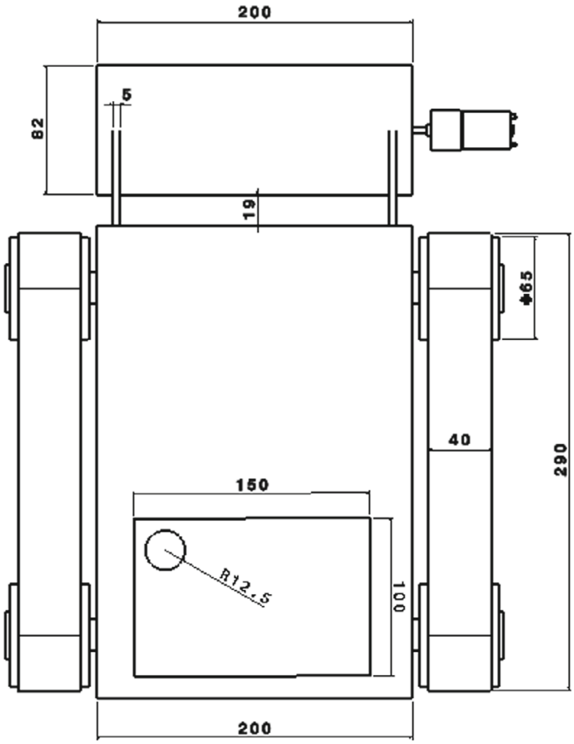
$$F = m \times a \tag{8}$$

r = radius of the wheel in mm, F = force in N, θ = angle, m = mass in kg, a = acceleration is m/sec^2, and T = torque in Nm. Using (7) and (8), the value of T is arrived as 0.097 Nmm.

4 Development of Robot

In this section, 2D draft model and CAD models of various components of the robot are explained.

Fig. 5 Top view of the robot



4.1 2D Draft Model

The 2D views of the virtual model of the robot are shown in this section. For fabrication of the robot, top view, front view, and side views are required. Figure 5 shows the top view, Fig. 6 shows the front view, and Fig. 7 shows the side view of the robot.

4.2 CAD Models for Development of Robot

Motor for Traction. Based on the calculations, the selected motor has a rating of 12 V at 600 mA. Four DC geared Johnson motors are selected for traction. Computer-aided design (CAD) model of motor is shown in Fig. 8. Specifications of the motor are shown in Table 1.

Wheels and Track for Traction. Four wheels are attached to the four motor shafts which are then fixed to the frame. The track belt is hooked on to two wheels on the right side and two wheels on the left side. The CAD model of the wheel is shown in Fig. 9. Specifications of the wheel and track are shown in Table 2.

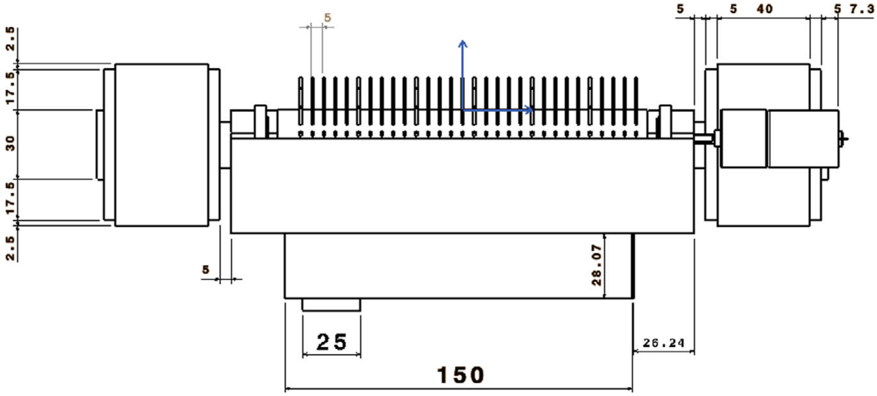


Fig. 6 Front view of the robot

Roller Brush for Cleaning. The CAD model of the roller brush is shown in Fig. 10. The roller brush is hollow on the inside and is embedded with smooth plastic bristles in a straight-line pattern with a spacing of 2 mm apart. Roller brush is attached to bearings on both sides having a standard diameter of 25 mm. Specifications of the roller brush are shown in Table 3.

Fig. 7 Side view of the robot

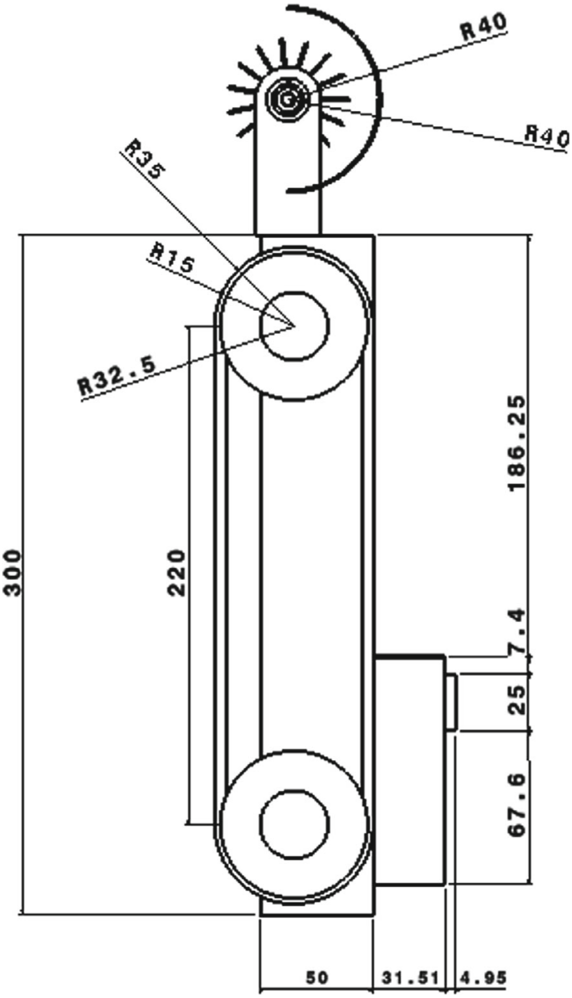


Fig. 8 CAD model of the motor

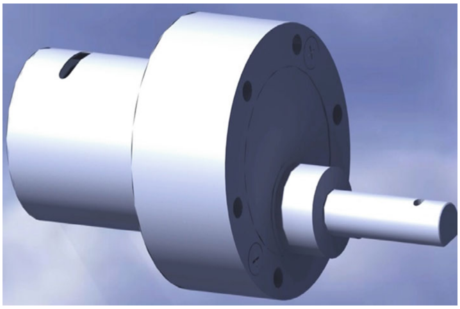


Table 1 Specifications of the motor

Parameters	Specifications
Speed	180 RPM
Voltage	12 V
Material	Metal
Torque	3.9 kgf cm
Diameter of motor shaft	6 mm

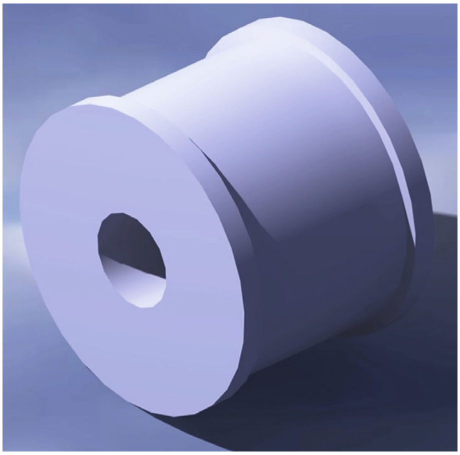


Fig. 9 CAD model of the wheel

Table 2 Specifications of the wheel and track belt

Parameters	Specifications
Diameter of wheel	60 mm
Inner diameter of wheel	6 mm
Thickness of wheel	40 mm
Wheel material	Plastic
Width of track belt	40 mm
Length of track belt	650 mm
Track material	Rubber

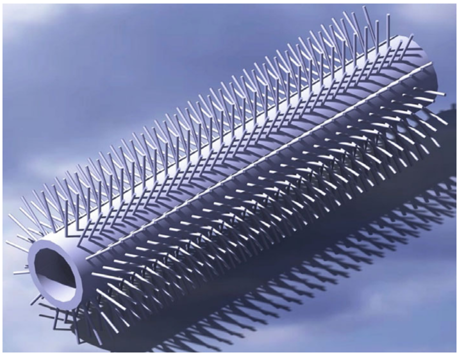


Fig. 10 CAD model of the roller brush

Table 3 Specifications of the roller brush

Parameters	Specifications
Length	300 mm
Diameter	35 mm
Material	Plastic
Distance between each bristle	5 mm

5 Conclusion

This paper discusses three design concepts for a cleaning robot, modelled and designed using CATIA software. Advantages and disadvantages of the design concepts are compared, and an optimal design is chosen. Concept 3 has been chosen as the optimal design as it provides thorough cleaning and consumes less power. The developed cleaning robot is capable of performing both wet and dry cleaning of the solar panel.

References

1. Sayyah A, Horenstein MN, Mazumder MK (2014) Energy yield loss caused by dust deposition on photovoltaic panels. Sol Energy 107:576–604
2. Archer MD, Hill R (2001) Clean electricity from photovoltaics, 2nd edn. Imperial College Press, London
3. Habib MR, Tanvir MS, Suhan AY, Vadher A, Alam S, Shawmee TT, Ahmed K, Alrashed A (2021) Automatic solar panel cleaning system based on Arduino for dust removal. In: 2021 international conference on artificial intelligence and smart systems (ICAIS), pp 1555–1558
4. MacKay D (2016) Sustainable energy—without the hot air. Bloomsbury publishing, USA
5. Khadka N, Bista A, Adhikari B, Shrestha A, Bista D (2020) Smart solar photovoltaic panel cleaning system. IOP Conf Ser Earth Environ Sci 463:012121
6. Nazar R (2015) Improvement of efficiency of solar panel using different methods. Int J Electr Electron Eng 7(1):12–17

7. Arshad R, Tariq S, Niaz MU, Jamil M (2014) Improvement in solar panel efficiency using solar concentration by simple mirrors and by cooling. In: 2014 international conference on robotics and emerging allied technologies in engineering (iCREATE), pp 292–295
8. Musthafa MM (2015) Enhancing photoelectric conversion efficiency of solar panel by water cooling. J Fundam Renew Energy Appl 5(4):10–14
9. Khuchua N, Melkadze R, Moseshvili A, Chitaia K, Melikidze G (2015) New-type solar concentrator concept—approach to reduced-cost CPV module technology. In: 2015 IEEE 42nd photovoltaic specialist conference (PVSC), pp 757–762
10. Sharma U, Singh B (2016) Grid interactive bidirectional solar PV array fed water pumping system. In: 2016 IEEE international conference on power electronics, drives and energy systems (PEDES), pp 1–6
11. Choi JS, Kim JH, Rim CT (2017) Incidence solar power analysis of PV panels with curved reflectors. In: 2017 IEEE 18th workshop on control and modeling for power electronics (COMPEL), pp 1–6
12. Khanduri N, Kukreti A, Shah N (2017) Implementation of solar time based sun tracking systems for mobile platforms and smart cities. In: 2017 IEEE region 10 symposium (TENSYMP), pp 1–5
13. Nicolae MS, Tudorașcu A, Nicolae PM, Saray R, Kall B, Rambolamanana G (2014) Optimization design of photovoltaic systems and improving their energy efficiency through a novel technology installation of the support. In: 2014 international conference on applied and theoretical electricity (ICATE), pp 1–6
14. Venkatnikhil A, Shama R, Naveenkumar KH (2023) Rover robot for solar panel cleaning and monitoring. In: IEEE North Karnataka subsection flagship international conference (NKCon), pp 1–5
15. Mazumder MK, Sharma R, Biris AS, Horenstein MN, Zhang J, Ishihara H, Stark JW, Blumenthal S, Sadder O (2011) Chapter 5—Electrostatic removal of particles and its applications to self-cleaning solar panels and solar concentrators. In: Kohli R, Mittal KL (eds) Developments in surface contamination and cleaning. William Andrew Publishing, Oxford, pp 149–199
16. Mondal AK, Bansal K (2015) A brief history and future aspects in automatic cleaning systems for solar photovoltaic panels. Adv Robot 29(8):515–524

Faster Cool Down of a Reefer Unit by Optimizing the System Losses Through Experimental Investigation

A. K. Goel and Somnath Sen

1 Introduction

A cold chain is the part of various segments, such as agricultural, industrial, and commercial and transportation. The energy consumption in case of refrigeration is the biggest part of the total energy requirements in preprocessing, refrigerated storage, transportation, retail, and end-user's consumption of the agricultural products [1]. The energy required in the agricultural segment is esteemed to be about 50% of the total energy consumed.

In order to minimize unnecessary energy waste in refrigerated container system, it needs to be designed to be energy efficient and provide high cooling capacity to ensure rapid pull down to carriage temperature and to maintain product quality [2]. Improper operation and design cause a significant waste of energy [3]. This avoidable waste of energy results in unnecessary economic loss. Energy use in a container is affected by the amount of heat the refrigeration equipment must remove, packaging designs, and the efficiency of the equipment [4]. Lawton et al. [5] justly observe two developments improving the energy efficiency of reefer units: hardware improvements and software solutions. Traditional control in chilled mode runs the compressor continuously and always runs the evaporator fans in maximum speed. It aims to improve chilled mode energy efficiency by avoiding inefficient part-load compressor operation and optimizing evaporator fan speed with heat load, without impairing product quality. In view of the growing fleet, rising fuel prices, and growing concerns about greenhouse gas emissions, there is an increasing interest in the energy efficiency of reefer units (e.g., [1, 5]) [6].

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In the present study, an existing reefer unit was considered for the evaluation. The purpose of this study is to reduce the time of achieving the desired temperature inside the container. The reduction in time would ultimately help to reduce the overall vaccine carrying cycle time. The study also involves the investigation of issues through fault-tree diagram analysis to find out the real root cause.

Reefer system was fitted in an eight feet (ft) container for vaccine carriage. The reefer unit consists of indoor unit which is fitted inside the container and has evaporator in it and the outdoor unit—fitted outside the container and has the condenser and fan. Both these units and compressor were connected through pipes and hoses. As per standard requirements from customer, the expected time is less than 2 h to reach − 20 °C temperature inside the cabin at 1500 engine rpm condition. However, it was observed during the operation that cabin temperature does not reach to the desired level within 2 h. Therefore, the baseline system was tested in a climatic chamber under certain conditions, and results were obtained. Detailed root cause analysis was carried out to figure out the concern areas. Based on the analysis, the most probable causes were investigated, and good improvement was observed in overall results of cabin temperature.

2 Types of Refrigerated Vans and Trucks

Typically, the refrigerated vans and trucks are divided into majorly two segments—vehicle-powered and self-powered. Vehicle-powered refrigerated vans and trucks are those that take power from vehicle engine to run the AC compressor while there is a separate engine (diesel) dedicated to run the compressor in self-powered reefer. The self-powered reefer vans and trucks also have electric motor which often powers the compressor in standby mode. In general, the self-powered reefer unit is used where the capacity requirement is very high and the container size is large. Vehicle-powered reefer is used for container size starting from 8 to 24 ft, and beyond that up to 32 ft self-powered unit is used. In terms of application, reefer unit can be classified as fresh and frozen, typically container temperature of 0 °C considered as fresh/chiller application while beyond that up to − 25 °C container temperature is considered as frozen. Based on the types of perishables, fresh or frozen is utilized; however, in each segment of vehicle-powered or self-powered, there are two types of application present depending on the market requirement and manufacturer product ranges. For a full range of product portfolio, starting from 6 ft container to 32 ft. container, fresh and frozen reefer units are available to cover the entire ranges of food items, medicines, vaccines, diary product, and meat products.

Based on the shipment needs, refrigerated vans are categorized into insulation van, chiller conversion van, semi-freezer van, and full-freezer van. Insulation van does not contain refrigeration system, but they are adept to keep the goods cool as long as possible depending upon the insulation type/quality or thickness. Chiller conversion vans are essentially with refrigeration unit and effectively maintain the low temperatures but not below zero storage limit. Meanwhile, semi-freezer can transport frozen foods and other items that must stay below zero degree centigrade. Among all the different types of refrigerated vans, full-freezer vans are those which allow significant freezing, and these are used for keeping the goods at freezing temperature.

Hybrid and eutectic are other types of refrigerated vans that are used in order to reduce the emissions and saving power. Typically, the hybrid system is used in case of distribution center to city, whereas the eutectic reefer is used from farm to warehouse where there is power shortage and no facility to get electricity. It also saves fuel as the eutectic plates are charged by electric compressor during the night stay.

From installation point of view, there are two types of condensing unit, namely nose mount and undermount, and based on the vehicle architecture, the mounting is decided.

The insulated compartment is divided into single zone temperature, dual zone temperature, and multi-zone temperature compartment to accommodate the wide ranges of needs to store the goods in a single container. In general, multi-temperature compartments are not available for small size container.

3 Reefer Application

Reefer containers are suited for temperature-controlled cargo and needed refrigeration while in transit. These can be considered as refrigerators in which goods are transported without being spoiled on the way. A reefer container is a type of a refrigerated freight container. Diesel generators are primary source of power for a reefer container during the voyage. Reefer containers are capable of maintaining the temperature in the range of − 65–40 °C. The circulating water is used to remove heat from the condenser in the absence of ambient air cooling.

Reefers enabled the availability of fresh goods anywhere in the world. Thereby, it has helped the trade of perishable items significantly. Reefers maintain the quantity and quality of goods and make it available fresh to the demand supply chain anywhere in the world. The prescribed temperature inside the reefers is maintained by circulating a specific temperature-controlled air inside the cargo space. The cargo loading method and packaging affect the air circulation. The packaging, loading, and temperature requirements are specific for a type of cargo. Particularly, a chilled cargo is distinct from a frozen cargo as the air circulation requirements are different.

The packaging of a chilled cargo carrying meet used must have ample vents for air circulation. The circulating air removes moisture, heat, and gases from the cargo. The air circulation is needed due to atmospheric heating and heat generation inside the cargo. The fresh vegetables and fruits are transported in the frozen cargo. Therefore, respiration and airflow requirement are typical. Here, the air should flow on and around the commodity removal of respiration gases such CO_2 and C_2H_4. The desired airflow is achieved by stacking cargo without leaving space between

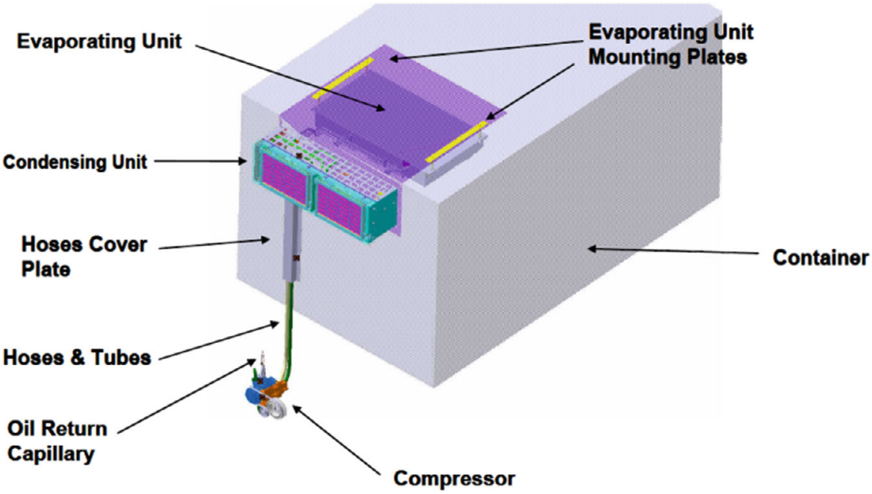

Fig. 1 Reefer system

the walls of the container and the packages. Since there is no heat generation in this cargo, the outside heat can be removed by a fan.

3.1 Reefer System

Figure 1 shows the schematic of the reefer system that was used for the experiments. Evaporator unit is placed inside the container, and condenser unit is placed outside the container just above the driver cabin. Compressor is placed near to the engine and connected with hoses and pipes with evaporator and condenser. Condenser gets ram air as well, and however, two axial fans are used for proper airflow over the core (Fig. 2).

Airflow gets sucked by these fans and comes out of the unit from the backside. Suction hose and discharge hose are exposed to the outside environment and part of it goes near to the engine area. So, it has high chance of heat pickup from the engine (Fig. 3).

4 Experimental Setup

Experimental setup was prepared as shown in Fig. 4. The container is made of 125 mm thick insulated panel. The condenser unit was placed outside the container, and the compressor was kept on a bench. As there was no engine, the compressor was run by an AC motor, and compressor RPM was adjusted by changing the frequency of