INTERNATIONAL JOURNAL OF
ENERGY AND ENVIRONMENT

Volume 4, Issue 5, 2013 pp.895-902
Journal homepage: www.IJEE.IEEFoundation.org

Atmospheric ice monitoring system operation at remote locations in cold region

Muhammad S. Virk, Taimur Rashid, Mohamed Y. Mustafa

Department of Technology, Narvik University College, Norway.

Abstract
The problems encountered in installation, maintenance and operations of equipment in the cold climate regions are far more complicated than others. The contributing factors and problems that can affect the system operation and performance should be identified, assessed and focused within well-defined parameters before its installation in cold climate regions. The harsh cold environment, could not only directly impact the system performance, but can also indirectly contributes to the associated factors, which could result in the delayed maintenance and system monitoring activities. This paper describes the issues related to meteorological ice monitoring system's operation in cold environment and also practical problems are identified and assessed, based on their impact on the overall system performance. The attributing factors causing such problems are overviewed and relationship between key parameters and system performance is discussed.

Keywords: Meteorological system operation; Ice monitoring; Cold region; Logistic.

1. Introduction
Monitoring and instrumentation systems are one of the prime necessities for research and development activities in cold climate regions. Making a system operational in harsh cold environment is a major milestone in achieving the desired outcome, but the real challenge lies ahead, where sustaining of installed system performance is most critical. The performance of the same equipment in two different climatic conditions might be similar during initial phase, but as the time progresses the performance might vary to a considerable extent, hence mean time between failures (MTBF) of the system becomes questionable. The installed system in the cold environment is subjected to various types of metrological conditions [1], such as storms, rain, variable wind conditions and ice/snow are among the major environmental factors, whereas the geographic position of the installed equipment also accounts for the localization factors, challenging the equipment life and related performance parameters.
Data collection and its post processing is more often an essential requirement in remote areas, where the accessibility is not always easy, as the number of trips to the remote site is less frequent. The lack of access to the site allows the exercisable option to collect the data on site followed by its retrieval after certain periodic intervals ranging from months to years. This methodology is followed in majority for the analysis of data in harsh climatic regions, but it also poses a major threat of lack of timely response to equipment maintenance. The down time of the site equipment could be completely unknown due to unawareness of equipment health. More often logistics issues indirectly causes the delay to access the site, which can also disrupts the chain of planned and coordinated activities of maintenance or routine

checkup. During such circumstances, it is observed that occasionally the equipment's non serviceability is revealed at the time of planned data-retrieval event, which leads to the loss of valuable records and cost in terms of time delay and resources.

The unpredictable nature of the climatic changes leads to uncertain behavior of the equipment, which can ultimately leads to the missing project timelines, loss of significant data, excessive utilization of resources and capital. Therefore, there is a dire need of translation of the practical problems faced during integration, installation, operations, monitoring and periodic maintenance activities of the measurement and instrumentation systems installed at remote sites in cold regions. The experiences acquired regarding the impact of cold climate on measurement and instrumentation systems (in urban and rural regions) can be formalized in the said perspective. Equipment designers have always been challenged by the need to keep equipment operational in extraordinary environment of the cold regions. The objective of this paper is to discuss the issues related to meteorological ice monitoring system operations in cold environment, where practical issues are highlighted based on their impact on the overall system performance.

2. System's operations in cold regions

The systems installed in the cold climatic conditions are subjected to the direct or indirect exposure to the harsh weather and environment affecting their performance and resulting to the intermittent or unreliable behavior. Focusing on addressing problems of the overall performance, it is essential to categorize the system's equipment with respect to individual element's exposure to the environment. Generally equipment of a standard system can be sub- divided into three major categories namely:

a) Passive sensing equipment
b) Monitoring and central computing system
c) Power supporting system

Figure 1 shows the schematic over view of the standard equipment categorization and interface. The *passive sensing equipment* generally consists of mechanical/electrical sensors with some associated electrical circuitry and has direct exposure to the weather and climatic conditions. The *monitoring and computing systems* comprises of embedded systems with in- house power converters to cater for the power requirements and generally are housed inside the protective casing and have indirect exposure. The *power support system* is main power/energy source, which could be sourced from conventional power system or the independent power supplying unit or based on solar energy. These power supporting systems have both direct and indirect exposure to the harsh conditions. Furthermore the interface links between these units are data and power based. Data links might include the Ethernet/serial links with supporting routing cables or interface panels, whereas power links have distribution panels, supplying power requirements to the computing and sensing equipment. Interface links along with power support systems have direct and/or indirect exposure to climatic conditions and they are under sudden transitional states, hence are most vulnerable to degradation and failure.

The dimension of operational problems faced in cold climate is quite different from the operations in normal conditions operating areas. More often the factors not significant at all in the normal conditions become extremely critical in cold climate regions. The operational problems generally faced in cold regions can be divided into following categories, which are of prime importance to consider.

a) Logistics
b) Human efficiency while maintenance
c) Power source breakdown
d) Erroneous equipment integration in weather protection perspective (winterization)
e) System health monitoring
f) Improper maintenance tools
g) Communication
h) Anticipation to unforeseen errors

In addition to the above mentioned operational issues, following are the major attributing factors for the degraded performance or permanent failure of the system's operation in the cold regions.

a) Frequent weather changes (temperature, wind speed/direction, wind chill factor).
b) Accreted ice loads (power extensions, electrical connections).
c) Equipment material.
d) Data wire breakage at connection points as they become brittle with the frequent and sudden transitions in below/sub zero atmospheric temperature.
e) Difficulty in level of access to the site due to unpredictable weather conditions and terrain.

f) Lack of preparedness to unexpected troubleshooting problems.
g) Non-frequent equipment monitoring.
h) Lack of accustomed maintenance tools.

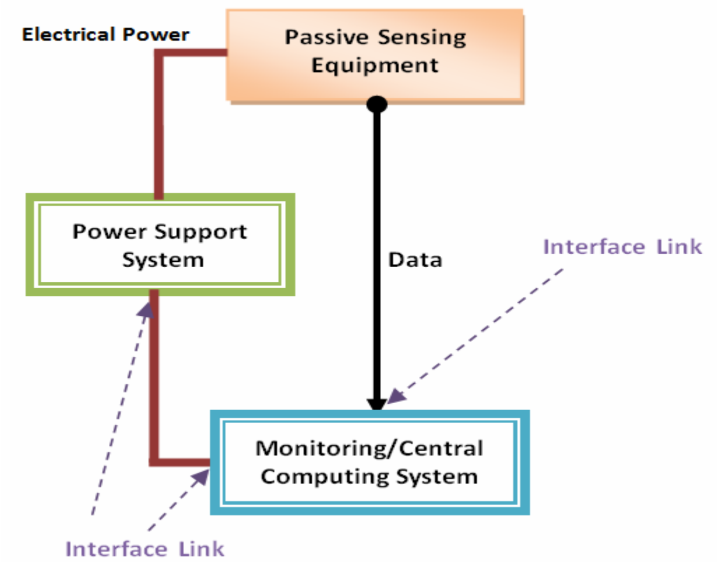


Figure 1. Schematic overview of standard equipment categorization and interface

3. Case study: Ice monitoring station's operation at Fagernsfjellet

A meteorological atmospheric ice monitoring station was designed within the ColdTech-RT3 project at Narvik University College, Norway, and was installed at the mountain, 'Fagernsfjellet (1007 m.a.s.l., 68° 25'20'' N, 17°27'26'' E)' located east from the Ofotfjorden and towards the north east from Beisfjorden on the western coast of Norway. Figure 2 shows the location of ice monitoring station of Narvik University College, whereas Figure 3 shows the ice monitoring station used in this study in both iced and ice free conditions. The mountain faces open sea from the south across the SW and to the west. This region is affected by gulf streams flowing across the North Atlantic Ocean. Air masses related to these streams are usually humid and have air temperatures favorable for atmospheric icing during the winter season (-25< T ºC < 0). The main goal of the mentioned ice monitoring station was to utilize experimental and mathematical tools jointly to better predict the expected upcoming icing loads and events, which would help in better planning for cold climate regions and would reduce the losses due to severe icing loads on equipment and structures.

The ice station comprised of a multifunction weather sensor along with ice mass and rate monitors, while a robust industrial scale data logging system was used for data-logging over a longer period of time. Table 1 describes the main components used for the HiN ice monitoring station.

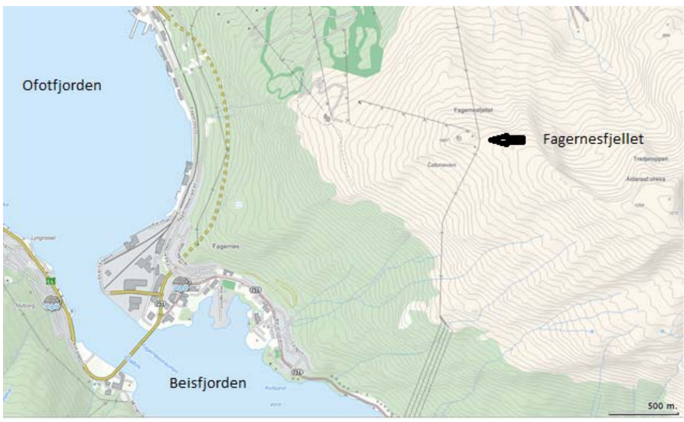


Figure 2. Map of Fagernesfjellet showing the topography of the region and location of HiN icing station

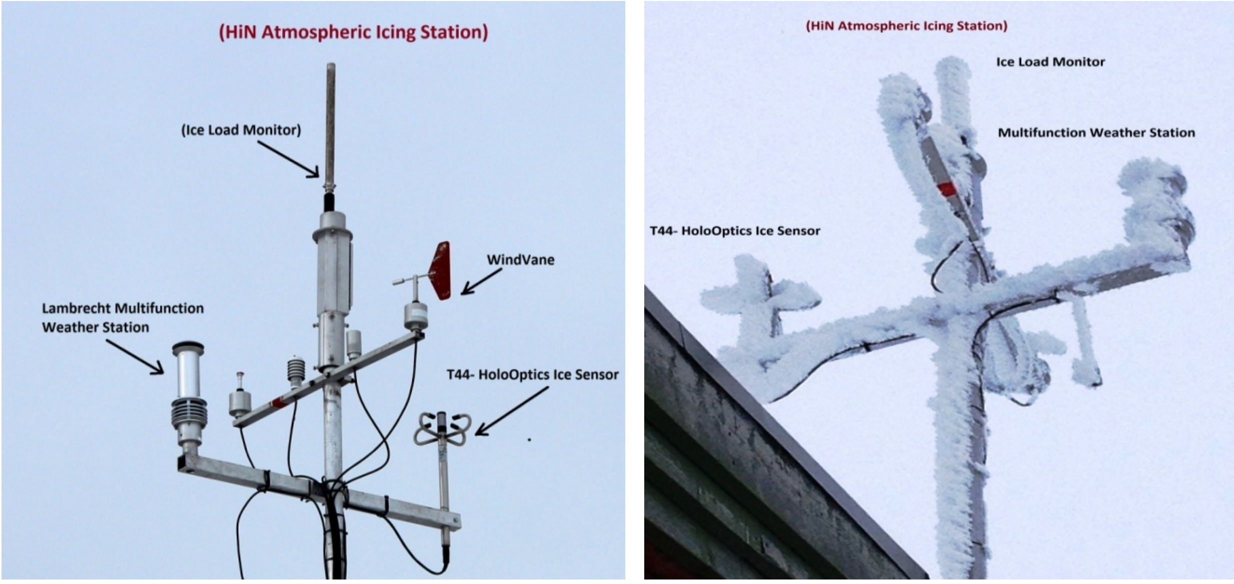


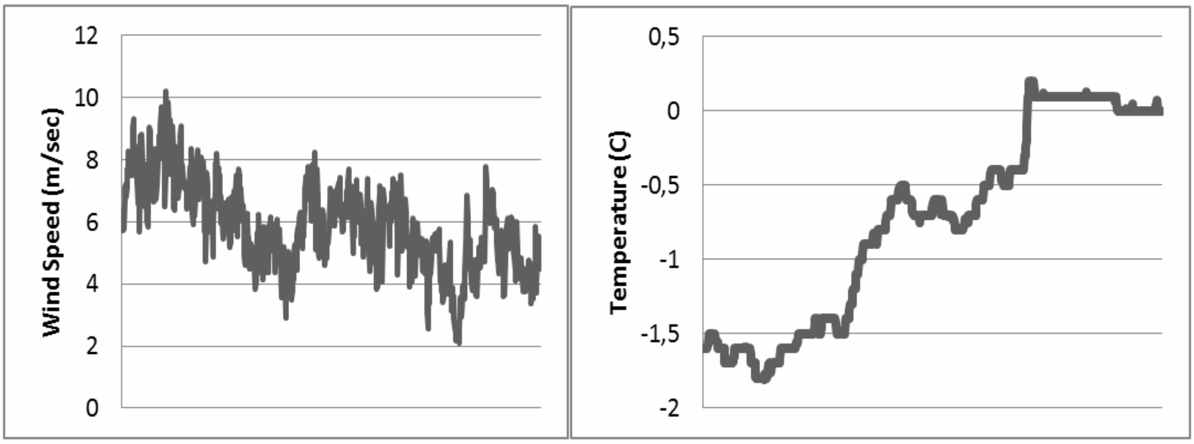
Figure 3. HiN Atmospheric icing station at Fagernsfjellet, Norway

Table 1. Major components of the HiN ice monitoring set-up

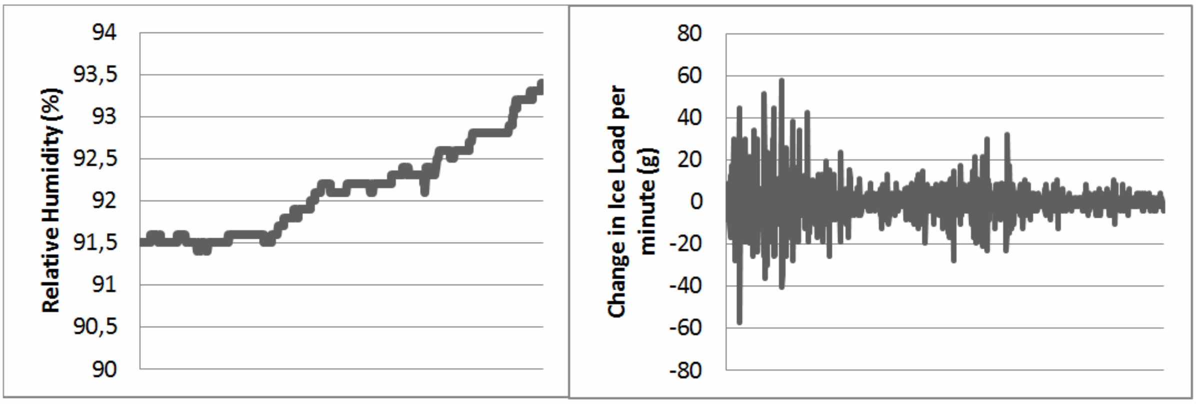
Manufacturer	**Model**	**Measurement**
Combitech	Ice Monitor	Ice mass
Lambrecht	EOLOS-IND	Wind speed and direction, temperature, humidity, pressure and dew point
HoloOptics	T44	Icing rate and type
Campbell Scientific	CR-1000	DAQ system

The data acquisition (*DAQ*) system and dc-power distribution/supply units (used for icing station) were housed inside the small cabinet mounted inside the available facility at the Fagernsfjellet, utilized for skiing and tourism. Main power source for this station was used from the existing facility at the Fagernsfjellet. To have a quality check on the icing station data, icing station was planned to be inspected periodically after its installation, but could not be accomplished several times due to logistics, harsh weather and associated facility's maintenance problems, which was also linked to the alternative mode of transportation to the site (*cable car and snow bikes*). The equipment installed could only be tested after four month of its installation and it was found that multifunctional weather sensor (*Lambrecht ELOS*) was unserviceable, not providing any output to the data logger system. This leaded to the loss of valuable metrological data (wind speed and direction, temperature). The equipment maintenance checks were performed in more details and after its retrieval, thorough data analysis revealed that multifunctional weather sensor stopped functioning after 2 months from its installation. Initial investigation at the station site disclosed that heavy ice deposition on the exposed components of sensor, power extension (interface) and frequent power break downs of the associated facility (through which the main power was supplied) caused the malfunctioning of the weather senor.

Although sensors used as part of the ice monitoring station were designed to withstand the cold and harsh weather conditions, but still weather sensor malfunctioned at extreme cold conditions. Though the minimum atmospheric temperature reached at -25^{o}C in the installation area and varies considerably, the equipment got unserviceable at 0^{o}C, it is worth mentioning here that weather sensor also worked at -25^{o}C during this study, but analysis of atmospheric data for last 12 hours before the start of malfunctioning of weather sensor showed that at time of its crash the atmospheric temperature was only 0^{o}C, average wind speed was 6 m/sec , relative humidity was 93.5% and most importantly the average accreted icing load on ice load monitor were quite high. Analysis of metrological parameters over period of last 12 hours confirms the heavy icy conditions before/at time of malfunctioning of weather sensor. Atmospheric metrological parameters for last 12 hours before the crash of weather sensor have been presented in Figure 4. This failure has raised questions on standards defined for designing of the equipment's for cold regions.



(a)



(b)

Figure 4. (a & b) Metrological parameters variation on icing station location for period of last 12 hours before malfunctioning of weather sensor

It is observed that temperature was generally below freezing. It is also observed that the dew point was less than average temperature for the last few hours, which can be interpreted as a cause of freezing of the water droplets in the air mass blowing across the weather station. Those reasons coupled with the wind data indicating the presence of water vapors in the air blowing from the sea and dropping temperatures and dew point to below freezing will cause ice accretion once the droplets get in contact with freezing particles or surfaces such as the icing station or other objects in the region.Fluctuations are observed in ice load measurements, but those fluctuations are in correlation with variations in humidity. The ice load readings are highest at lower humidity due to the fact that some of the humidity in the air is transformed into accreted ice on the system components.Further investigations were carried out to track down possible reasons of this failure. Analysis showed a combination of various aspects that could possibly lead to the atmospheric icing station system's failure in harsh conditions. Following are the noteworthy causes in this regard.

3.1 Equipment's MaterialFailure

One possible causes of the sensor malfunctioning can be the material properties of the sensor. The sensitivity of problem encountered in cold regions is largely a function of materials used in the equipment construction and degree of stress, under which it is operated. Some materials get stronger, at the cold temperatures (Aluminum) and are often preferable for the cold weather service. Other materials can be altered to make more cold tolerant [2, 3]. Yield strength of material increases as the material gets colder while the ultimate strength goes opposite. Such change in material property is closely related to the ice load, wind chill factor and effective atmospheric temperature. When exposed to the cold temperature, rate of cooling for an exposed surface depends not only on the atmospheric temperature, but also on speed of the wind. This refers to the wind chill factor, which is the rate of heat removal, contrary to the temperature. Strong wind speeds lead to an increased wind chill factor, which means an increase of heat removal from equipment surface. This affects the thermal conductivity and molecular structure of the material.

3.2 Equipment winterization

Equipment winterization can be another possible reason of this failure. As it is impractical to suspend operations at the inset of the cold weather, therefore equipment must be properly winterized to make it possible to use during winter and reduce cold related wear and breakage. The degree to which a piece of equipment must be winterized varies with the severity of the working environment. If temperature below freezing occurs only sporadically and for short periods of time, winterization may be ignored, but if longer periods of below freezing temperatures are encountered every year, then extensive winterizing is not only justified, it is essential [4].

3.3 Power cable insulation

Electrical insulation of external power cables can be another possible cause of system failure. Many of the insulations normally used on electrical wires and cables are not compatible with colder temperatures. Cracking of the insulation exposes the conductor to the environment creating a serious hazard. This is particularly a problem for the extension cords used outdoors. Several polyvinylchloride (PVC) insulations that are commonly used as electrical insulation do not withstand flexing at low temperatures, as at temperatures below -30^{o}C, PVC insulations cracks and peels leaving exposed conductors which can cause a short circuiting or develop grounding problems making data unreliable [2, 5]. Figure 5 shows example case of the ice accretion on cable used for the ice monitoring station.

Figure 5. Icing on external power cable

3.4 Power breakdown

Power breakdown or misstatement of the external power source can be another reason, as electricity breakdown can also lead to such malfunctioning. The frequent power breakdowns were reported at the local facility of icing station. One of the power failures was reported in second week of December, 2012, on the other hand erroneous readings were observed in the data logging system in the same period with latest correct readings of 2^{o}C air temperatures with icing load. After this, only icing load remained consistent as the only reliable data and rest of the parameters were entirely erroneous. Second power failure occurred in 1st week of March, 2013 when equipment was no further harmed hence maintaining its previous status.

3.5 Electrostatic discharge (ESD)

The electrostatic discharge phenomena could not be fully neglected in weather sensor breakdown. For snowstorms, temperature gradients in the ice particles produce charge separation because the concentration of H+ and OH- ions in ice increases rapidly with increasing temperature, and also H+ ions are much more mobile within the ice crystal than OH- ions. As a result, the colder part of an ice particle becomes positively charged, leaving the warmer part charged negatively [6]. The resulting electrostatic phenomena due to blizzard can be hazardous for the control circuitry of the inside the sensor module, provided the said consideration is not catered in the design. Over and above this fact, the proper maintenance of earthing at the site becomes all the more critical in this perspective.

4. Considerations for safe system integration, installation and operations

Instrumentation and measurement system installation in the remote sites of cold regions can be a challenging task. Based on the practical problems discussed above, it is pertinent to vigilantly execute the planning, integration, installation, operations and maintenance in perspective of the relationship and preemptive measures. To achieve a successful and reliable working system in cold climate region some considerations are too critical to ignore.

4.1 System's health monitoring

A mechanism could be defined for continues health monitoring of the installed onsite system. Since the frequent onsite visits are mostly not feasible, remote monitoring through a possible wireless medium could be an exercisable option. The challenges in wireless monitoring are based on the selection of the appropriate RF and GPS media and locations of base station and onsite equipment. Remote health monitoring in the cold climate region can help to reduce equipment down time and will eliminate the surprise factor of unattended faulty equipment.

4.2 Appropriate winterization/protection

The protection of interface links and power support system in specific should be carefully executed to avoid any disruption. In cold climate region, uncertainty is always there for the smooth operation of the system. The system installed becomes vulnerable to the harsh environment, if inappropriate protection and insulation is used in integration design.

4.3 Backup system provision

It is always useful to have a backup of the passive sensing and power supporting units (based on the feasibility analysis). The backup system can amicably provide a useful alternative for seamless operations reducing the logistics and equipment down time cost. However it should be ensured that the backup system should be a complete redundant system without impacting the performance of the primary system.

4.4 Appropriate equipment selection

Selection of appropriate equipment is important for the safe operation in cold regions. The equipment should be tested and certified for the operation in cold and harsh environment. In most of the cases the customized integration will be required for the specific requirement; hence system integration should take account of all the required standards ensuring to nullify exposing the weak links.

4.5 Streamline logistics

The logistics dynamics is totally different in cold climate region as it requires more time, cost and efficient coordination. It might also happen that the planned logistics associated with the onsite maintenance activities could be hampered by poor weather conditions. All the links involved in the logistics and transportation should be streamlined and alternative plans should also be considered for timely maintenance and operations.

4.6 Human efficiency and maintenance

The onsite maintenance in extreme weather conditions can easily reduce the human efficiency, while performing maintenance activities. Therefore proper clothing and maintenance equipment should be selected for operation in cold regions.

5. Conclusion

Based on the experience of installation, operations and maintenance of ice monitoring station at Fagernesfjellet, it was evident that factors leading to the equipment failure in cold climate region are generally overlooked and ignored. The indirect contributing factors such as logistics, transportation and access to the site become vital, which demands remote monitoring of the system in effective manner. In addition to that anticipated and preventive maintenance culture should be invoked as a regular practice, which could encounter the unpredictable impact of harsh environment upon the on-site system. The problem areas discussed can be utilized as a guideline in equipment integration, installation and maintenance viewpoint. Future work can be done in modeling the relationship amongst the problem areas discussed and associated attributing factors in perspective of the climate-exposure based equipment categorization.

Acknowledgements
The work reported in this paper was partially funded by the Research Council of Norway, project no. 195153/160 and partially by the consortium of the project ColdTech-Sustainable Cold Climate Technology.

References

[1] Foder., M.H. ISO 12494 – Atmospheric icing on structures and how to use it. in 11th International Offshore and Polar Engineering Conference. 2001. Norway.
[2] Dean R Freitag and T. McFadden, Introduction to Cold Regions Engineering. 1996, New York: ASCE Press. 725.
[3] Dutta., P.K., Behavior of materials at cold regions temperatures, 1988, U S Army Corps of Engineers, Cold Regions and Engineering Lab (CRREL): Hanover.
[4] Diemand., D., Winterization and winter operation of automotive and conctruction equipment 1992, U S Army Crops of engineers, cold region research and engineering lab: Hanover.
[5] D V Rosato and R.T. Schwartz, Environmental effects on polymeric materials. Vol. 1. 1968, New York: John Wiley & Sons.
[6] Shorter., J.L., The electrification of snowstorms and sandstorms 1963, 1963: Dept of physics Manchester College of Science & Technology.

