

Registration Seminar Report

On

**SYNTHESIS OF COATING AND ITS
APPLICATION IN HEAT TRANSFER**

By

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CERTIFICATE



This is to certify that the *Registration Seminar* presented by **Suparna Bhattacharyya (Roll 19CH92R06)** has been approved for submission. The broad area of research is “*Synthesis of Coatings and its Application in Heat Transfer*”.

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DECLARATION

I joined the Department of Chemical Engineering as an Institute PhD scholar on 2nd January 2020 under the guidance of Prof. Sudipto Chakraborty and Prof. Surjya K. Pal. Currently, I am continuing my research as a Prime Minister Research Fellow (PMRF) in the Department of Chemical Engineering, IIT-Kharagpur. The broad area of my PhD. research work is “**Synthesis of Coatings and its Application in Heat Transfer**”. I am presenting below the course work completed and work done during the period of 2nd January 2020 to till date.

Course Work Completed

The courses that are completed by me are as follows.

S. No	Subject Name	Subject No.	Credit	Grade
1.	English for Technical Writing	HS63002	4	B
2.	CFD Applications in Chemical Processing	CH62047	4	EX
3.	Techniques of Materials Characterization - II	MS60008	3	C
4.	Society, Science and Technology	HS51637	3	EX
5.	Research Methodology	HS60012	4	B

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Abstract

One of the highly used metals for engineering applications is steel. The strength, hardness and weldability of steel greatly depend on the heat transfer rate and cooling temperature. Steel is the manufacturing material of most of the industrial machineries. That includes small textile firms to giant aerospace and marine applications. Coating is also a stable method of enhancing and modifying surface morphology for various purposes that includes properties like anti-corrosion, anti-wear, anti-fouling, tribological properties and heat transfer applications.

The present study comprises of literature review and proposed objective and experimental procedure of synthesis of Electroless Nickel phosphorous coating that is coupled with copper to produce enhanced heat transfer applications. The application of heat transfer on steel plates is quite a promising research field. The areas is studied and framed in detail in the given work. Vast scopes and opportunities are there to explore in it with latest new thinking and novel processes. Working with various composite material of Nickel Phosphorous (Ni-P) to illustrate its various regime of application can be a potential future scope of the current study. Along with that how the use of additives, surfactant and nanofluids changes the basic properties of the coated surface can also be another fine topic to analyze. Moreover, these latest techniques will be quite helpful for further industrial and research applications. Hence, the researchers should explore in the current fields for different types of more such interesting outcomes in the coming days.

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1. INTRODUCTION

One of the highly used metals for engineering applications is steel. The strength, hardness and weldability of steel greatly depend on its heat transfer rate and cooling temperature¹. Most of the industrial machineries and its part are made up of steel. Its application ranges such a versatile regime that it includes our daily life used utensils to mighty fields of marine and chemical plant application^{2,3}. Thus, scholars keep on researching for decades to improve the structural morphology, hardness and weldability of this material. Coating is also a stable method of surface modification that enhances different properties of surface material thus making the surface material versatile to serve various purposes. Electroless coating was first developed in mid twentieth century and was popularized mainly due to the fact that the coating procedure needs absolutely no electricity. Thus, quite simple and cost-effective to execute. Along with that the coating and its composite alloys are having wide range of application⁴ which includes anti-corrosion, anti-wear, anti-fouling, tribological properties and heat transfer applications.

Due to its versatile usage, coating is used for lots of diversified fields. These not only includes the on-field services but also is helpful for offline works. It is way too helpful for structuring different material surfaces and effective microstructures.durability and structural suitability. Though some of the finest usage of coating is highly specific for applications like corrosion, wear protection, thermal applications etc^[5-8].Corrosion changes the mechanical property of substances. Along with that the corrosive material are harmful for environment and has extreme side effects for various applications. Various coating material has different deposition mechanism which is has good and bad effect on the depositing surfaces making the material suitable good for some purposes and not so suitable for others.

The procedure of coating showcases different advantages like mechanical stability, corrosion properties,biocompatibility (for biomedical applications), thermal rate control and enhancement of material behavior.But it is worth mentioning that these processes are highly purpose oriented. Thus along with great advantages⁹ there lies some disadvantages of coating processes like adverse effects, negative thermal effects (e.g., distortion, crack, delamination, etc.), destructive effects of loose atmospheric protection (e.g., penetration of inclusions and contaminations into the substrate) and

coating materials properties (e.g., melting point, availability in different forms of foils/powders/rods, biocompatibility, etc.) are the most crucial ones to be considered. Considering all the advantages and disadvantages¹⁰ of the procedure, it should always be noted that material selection for coating is the key step for serving the purpose. Different materials that are considered for coating materials are metalloid, metals, ceramic and polymers that are best in serving protective layers. Metal alloys and composite metals are also well known for forming coating solutions.

The present study is mainly focusing on development of electroless Nickel phosphorous composite together with copper (Ni-Cu-P) on the surface of mild steel AISI 1040 to enhance not only the cooling rate of the base material but also to improve its hardness and weldability. Moreover, the anti-corrosion, anti-fouling, friction factor and the tribological properties of the coating material is also characterized and observed properly.

2. LITERATURE REVIEW

2.1. Coating And its Type

Different materials are chosen to design and structure some targeted applications. The choice depends on some constraints like mechanical properties in the form of tension, compression, yield, torsion, fatigue, bending, and creep, desired functionality (such as friction properties, hydrophobicity, wear resistance), thermal properties (e.g., thermal expansion and conductivity to transfer heat flux), electrical conductivity, corrosion resistance etc. Along with that availability, safety, material cost and toxicity are one of the key features to finalize the material to design for the purpose. For example, silver is well known to offer high electric conductive surfaces, but these experiments demand huge amount of silver which is quite too costly^[11-15] Again Copper is famously a good conductive material for thermal and electrical energy, but it is having very low stiffness and wear resistant^[16-20]. In fact, the durability of mechanical parts of copper rotary cooling fins decreases due to high wear mechanism which decreases the life of the machine quite evidently^[17]. To overcome these challenges and to enhance material properties different methods like alloy wash, heat treatment and coatings are opted. The process of coating is considered to provide highest material improvement among these. The reason is its ability of cost effectiveness and its quite easy and versatile usage.

Coating is a surface application that is capable in offering several properties like corrosion resistance, wear quality enhancement, improved thermal properties, modified surface texture, wettability, hydrophobicity etc ^[18] Different types of coating processes are discussed vividly in the following.

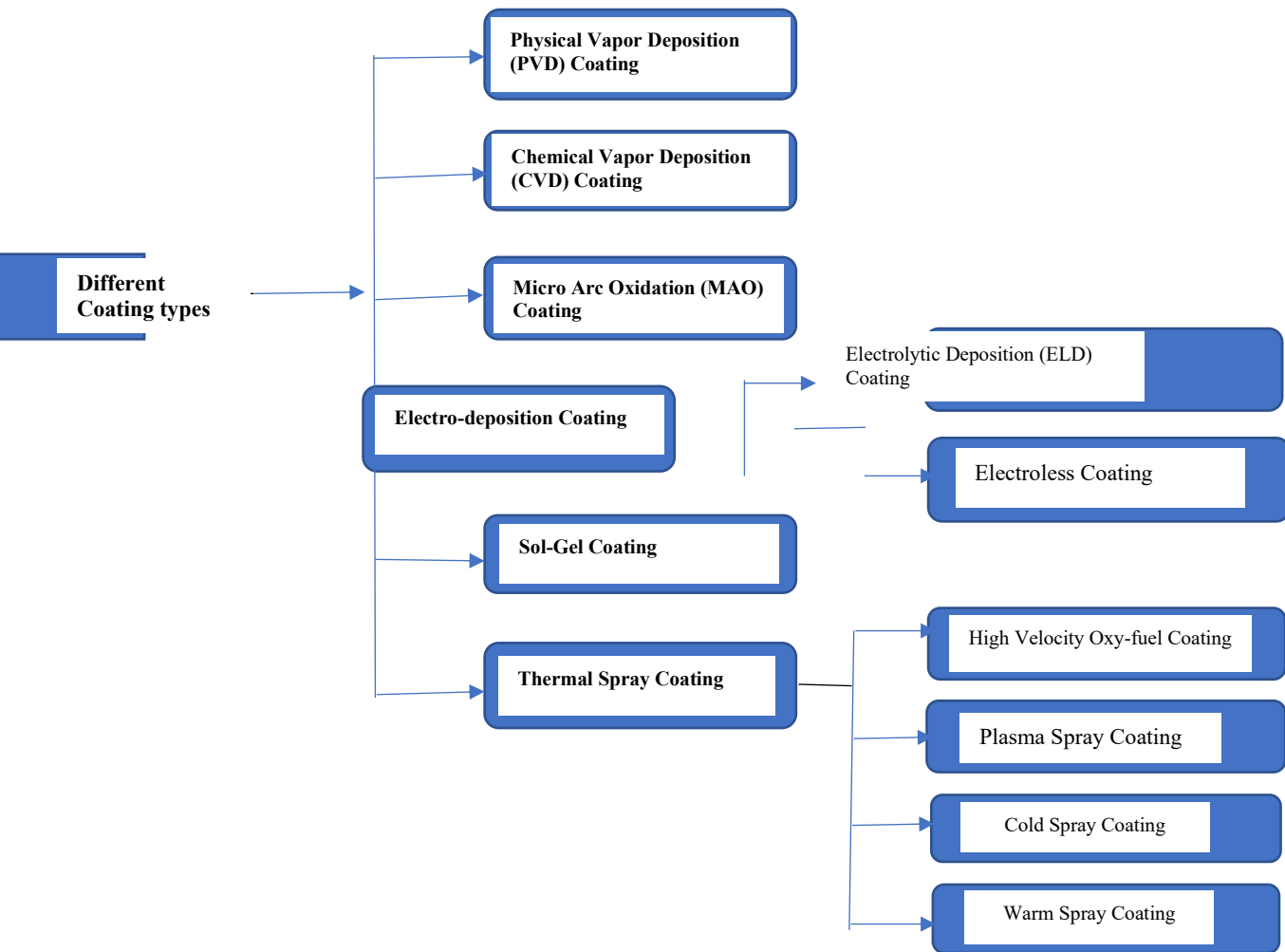


Fig. 1: Classification of different types of coatings

2.2. Electroless Coating

The term “Electroless” came from the fact that the method does not required any electricity to carry on. It is a controlled autocatalytic deposition in the form of continuous layers on a catalytic surface due to reaction of a complex compound and a chemically active reducing agent. This method is very helpful in forming film deposition with quite low thickness. Moreover, the process can be very simply executed [3,18,19,20]. Electroless Coating was first developed in the middle of the twentieth century by two inventors Brenner and Riddell [21-25]. From that era till today it has matured as an important topic of research mainly due to its various uses and applications. Its application range is quite versatile that includes from mighty aerospace usage to simple knitting needles. The reason for its wide range of application is its

property of great wear and corrosion resistance. Along with that the coating is also widely in use for electromagnetic interference (EMI)^[26], bacterial adhesion reduction^[27], membrane reactors^[28], cooling property enhancement and decreasing heat exchanger fouling ^[29].

2.3. Thermo-physical Properties of coating

Electroless Coating is not only effective as a corrosion resistant and with good friction and anti-wear properties, but recently the coating is having a wide range of application in modifying the surface properties of industrial metals like steel. Several research work can be proposed using this coating application to enhance the cooling and heat transfer properties of heat exchangers and industrial metals. Gherasim et al, reported the influence of flow factors like Nusselt no., Friction factor of water on modified plate heat exchanger under the flow regime of laminar and turbulent type (Recently studies showed the usage of sandblasting procedure to modify the surface roughness from 1.189 μm to 3.312 μm that enhances the cooling property of the heat exchanger ^[30]. Another study modified the metallic porous surface and analysed the heat transfer coefficient^[31]. Ahn et al generated a super hydrophobic surface using polymethyl methacrylate (PMMA) and boron nitride (BN) to study the critical heat capacity and antifouling phenomenon of steel materials. In a recent study the steel surface is modified using Al₂O₃ nanoparticles (1-4%) by Kabeel et al to increase the surface cooling capacity of the material ^[32]. Different other studies used nanofluids to enhance the heat transfer property of steel. Like Ravikumar et al²¹ increased the heat transfer coefficient using water alumina solution with several additives and surfactants. On the other hand, Chakraborty et al²² reported a maximum thermal conductivity enhancement of about 16% with respect to the base fluid (water) using double layered hydrocarbon of Cu-Al. A novel model is proposed by Sastry et al, better termed as percolation model that is capable of reporting about the thermal conductivity of materials having high aspect ratio like nanoparticles CNT, graphene GO etc. A study stated a maximum enhancement of 27% thermal conductivity using graphene based nanofluids where there is a monotonic rise of thermal conductivity along with the concentration ^[33]

2.4. Anti-Corrosion & Wear Resistant Properties

Electroless coating rank amongst the topmost to serve as an anti-corrosion and wear resistant material. Various binary and tertiary alloy coating techniques has been variedly used to produce enhancing anti-corrosion and low wear properties. Nickel-Phosphorous (Ni-P) has been reported to give the best result till date. It is been experimented that the corrosion behaviour of Ni-P coating depends on three principal factors (i) degree of amorphous state (ii) internal stress extent and (iii) percentage of phosphorous content. Phosphorous content mainly differs the crystalline structure of the material leads to a better corrosion resistant substance ^[3, 36-40]. This is the reason why high phosphorous content (12-14%) Ni-P coating is immensely used in marine and aerospace applications ^{41,42,43}. Another experiment revealed the enhancement of anticorrosion properties using 3.5% more phosphorous based solution compared to the simply prepared Ni-P coated materials ^{3,[44-46]}. However, electroless Nickel-boron (Ni-B) coating perform lower resistance against corrosion compared to Ni-P coating⁴⁷. Though inclusion of phosphorous (Ni-P-B) or a conductive material like copper (Ni-Cu-P)⁴⁸ or tungsten (Ni-W-P) within the coating ring increases the corrosion resistivity quite notably both in basic and 3.5% of hydrochloride acidic solution⁴⁹. Currently researcher are also working to infuse nanomaterials like TiO₂^{29,30,50}, Al₂O₃^{51,52} within the binary alloy chain forming the composite alloy enhancing the corrosion resistance and friction properties of the composites.

The property of wear is very much dependent on the corrosion. It is a fact that a corroded surface can never show good wear properties as well as wear definitely leads to corrosion. Many modern high-tech machineries are open to corrosive atmosphere like in chemical treatment plat, in marine applications etc. The important parts of these machineries definitely need good protection from corrosion and wear properties. Here the coating plays a vital role. Deposition of Ni-P coatings on a carbon fibre reinforced plastic (CFRP) substrate also increases its wear-corrosion resistance. This wear-corrosion resistance increased as coating thickness and phosphorous content increased and the polishing condition decreased ⁵³⁻⁵⁹. Another study states that the corrosive wear of the coating was seen to be linearly dependent on NaOH concentration, and the corrosive wear resistance of the composite electroless plating was superior to the Ni-P coating in any NaOH concentration (Liu, 2006)

2.5. Antifouling Properties

Since the 1980s, electroless plating has been treated as an operational technology of the surface modification, attracting widespread attention^{60,61}. The results prove that electroless Ni-P-based coating is an advantageous method for fouling inhibition⁶². The mass gain method⁶³ the calcium ion loss method⁶⁴, and the fouling resistance method⁶⁵⁻⁶⁷ were commonly used for measuring the deposition process of calcium carbonate fouling on materials surface. The surface is easy to be corroded and the oxidized surface is prone to form a “transition interface”, which works as a “bridge” to connect the matrix and fouling. The “transition interface” consists of corrosion or oxidation, and the lattice of the “transition interface” layer can be easily matched with the lattice of fouling. Therefore, the adhesion of fouling on the corrosion interface seems to be easier⁶⁸. Simultaneously, compared with uncoated pipe, the tube with electroless coating can significantly improve the property of condensation heat transfer, showing the coexistence of dropwise and film wise on most working conditions^{69,70}. Calcium carbonate is the principal component of fouling in industry. It is easy to adhere to the surface of the heat transfer wall to form fouling, affecting the heat transfer efficiency. The compactness and adhesion strength of fouling on the surface of heat exchange wall depends on its crystal structure^{71,72}

3. RESEARCH GAP

The following research gap have been observed after a detailed literature survey

1. Studying different types of quenching and cooling techniques are quite common but analyzing those on surface modified coated area is something where the research interference is quite scant.
2. Studies of Ultrafast cooling (UFC) on Ni-P composite coated steel surface and Ni-P composite nanomaterial coating is another interesting area to explore.
3. How the rate of heat transfer changes with use of different kinds of additives, polymers and surfactant based nanofluids.

4. OBJECTIVES OF CURRENT RESEARCH

The research objective that is shaped out of the thorough review study and the above stated research gap are as follows:

1. A detailed study of different types of heat transfer techniques using coated steel plate and a comparative study stating out of it.
2. Calculating heat flux and cooling rate after using basic fluid (water) and water mixed with several additives, surfactants and nanofluids.
3. Studying the corrosion resistant, antifouling and wear resistant characteristics of coating materials

5. EXPERIMENTAL

5.1. Synthesis of Coating deposition

Mild steel AISI 1040 which is a low carbon steel is used as substrate for electroless deposition. The samples are prepared according to the following measurements (based on the requirements of various tests):

30 mm x 30 mm x 6 mm. It is seen that the electroless deposition follows the profile of the substrate. Thus, before the deposition, the samples are grinded to a roughness grade of N5 ($\sim 0.4 \pm 1\%$ mm) (as per BS EN ISO 1302:2002). Subsequently, samples are degreased in soap water followed by acetone cleaning for 5 min and pickling in hydrochloric acid (HCL; 50%) solution for 2 min. Deionized water is employed to wash the samples between the steps. The substrates are activated by dipping for 8–10 s in warm (55°C) palladium chloride solution (i.e., 0.1 g/l of PdCl₂ and 0.1 ml of dilute HCL). This step is purposefully introduced to lower the initial energy barrier, thereby promoting the initial coating deposition rate. This also ensures good adhesion of the deposit to the substrate. The prepared samples are held with a string and immersed in the electroless Ni–P–Cu plating bath. The chemical composition and operating conditions of the bath used for the deposition are shown in Table 1.

Table 1. Electroless Ni–P–Cu bath composition and deposition conditions.

Chemical composition	Concentration/value
NiSO ₄ , 6H ₂ O (nickel source)	25 g/l
NaH ₂ PO ₂ , 2H ₂ O (reducing agent)	25 g/l
C ₆ H ₅ O ₇ Na ₃ , 2H ₂ O (stabilizer)	45 g/l
CuSO ₄ , 5H ₂ O (copper source)	1 g/l

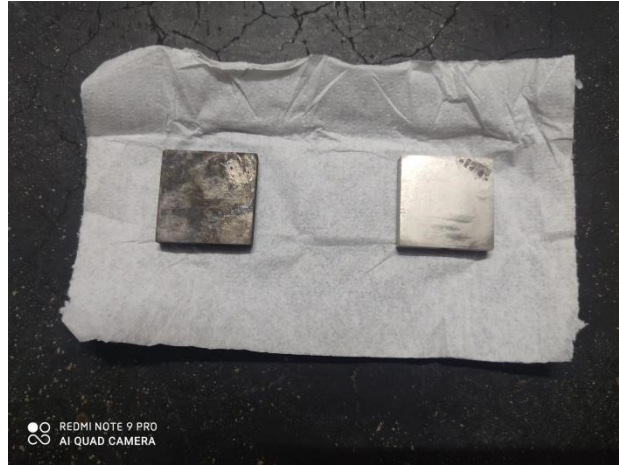
Operating conditions:

pH6 ± 0.5

Temperature85 ± 2°C

Plating duration..... 2.5 to 3 hours

Bath volume.....850 cm³



(i)

(ii)

Fig 2: Images of sample (i) before and (ii) after coating

5.2. Heat Transfer Analysis

A novel self-customized setup has been fabricated for carrying out our experiments on heat transfer. The setup has been illustrated by the following diagram Fig. 1. The experiment has been carried forward on a mild-steel AISI 1040 plate with dimension 30 mm x 30 mm x 6 mm. For the purpose of temperature measurement, three K type thermocouple having diameter of 2 mm each are inserted parallelly within the steel plate's cooling surface. The thermocouples are then connected to the data acquisition system in order to record the time-temperature history of hot steel plate. Then the recorded data are used to calculate the surface temperature and surface heat flux. The software that is mainly used for this purpose is commercially available INTEMP software. The heat transfer rate is studied between 0° to 200° C since, the structural and metallurgical changes in the atomic level takes place within this temperature range. For cooling the hot steel plate, circular spray nozzle with water and compressed air has been used. The muffle furnace is used for proper thermal soaking and heating of the steel plate at a temperature of 250° C. After heating the plate at the desired temperature, the steel plates are taken out of the furnace. The steel plate are then adjusted on a ceramic pad having groove shape etched out similar to plate. After that, the pump will be switched on and rotameter^{1,21} are used to adjust the definite flow rate. The process of heat transfer and cooling will start with the onset of solenoid valve. Below the nozzle a temporary block will be placed as an

shutter to prevent water flow on heated plates. It is removed once the flow gets stabilized. Different water and air flow rates are experimented with repeating the process and also using the additives, polymers and various nanomaterials.

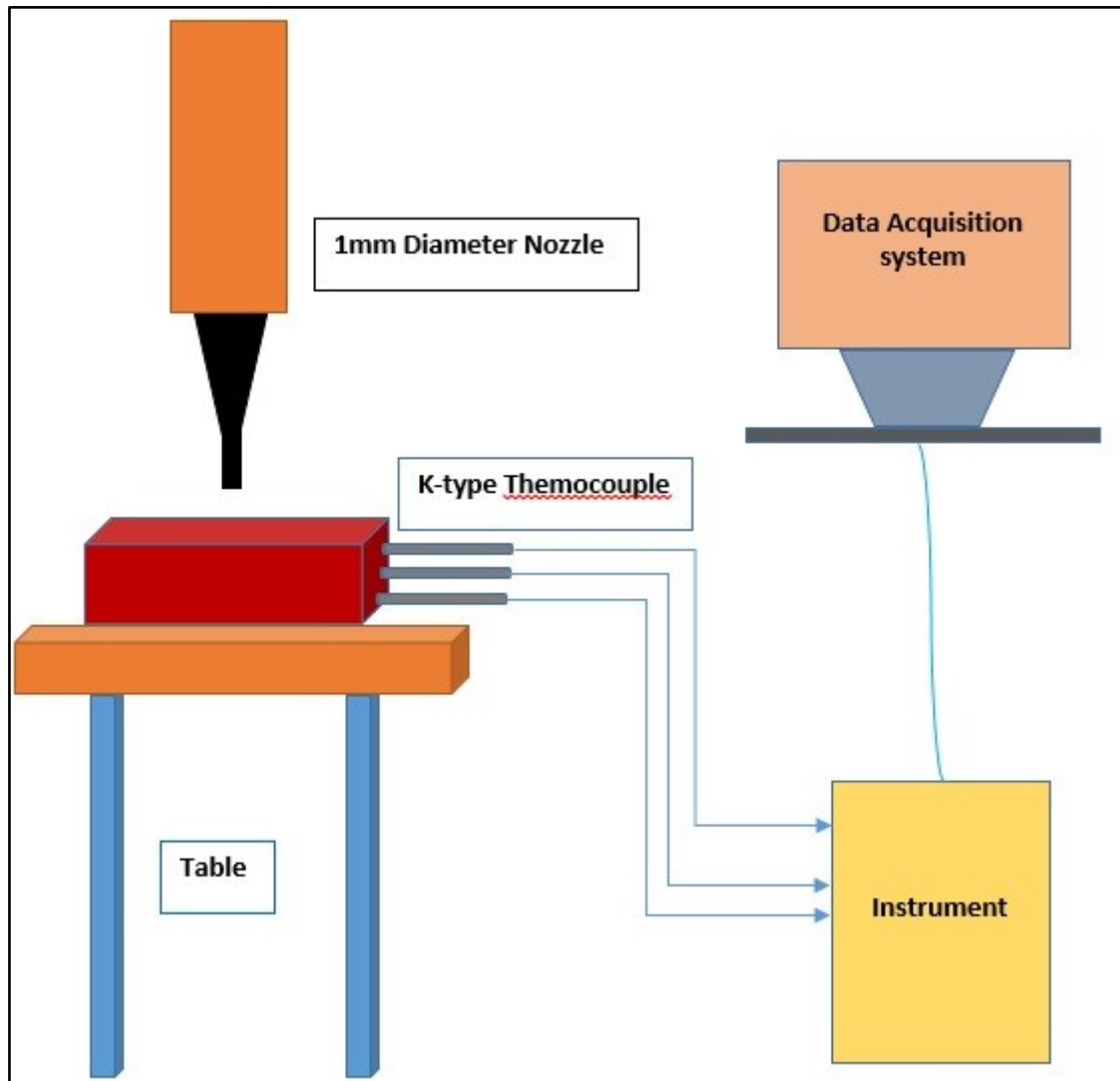


Fig 3: Schematic Representation cooling system with latest novel setup

6. RESULTS AND DISCUSSION

6.1. SEM Study

SEM Analysis of the specimens has been performed using a ZEISS SEM machine in secondary electron scanning mode. SEM images reveal that all components in the coating are evenly distributed on the steel surface.

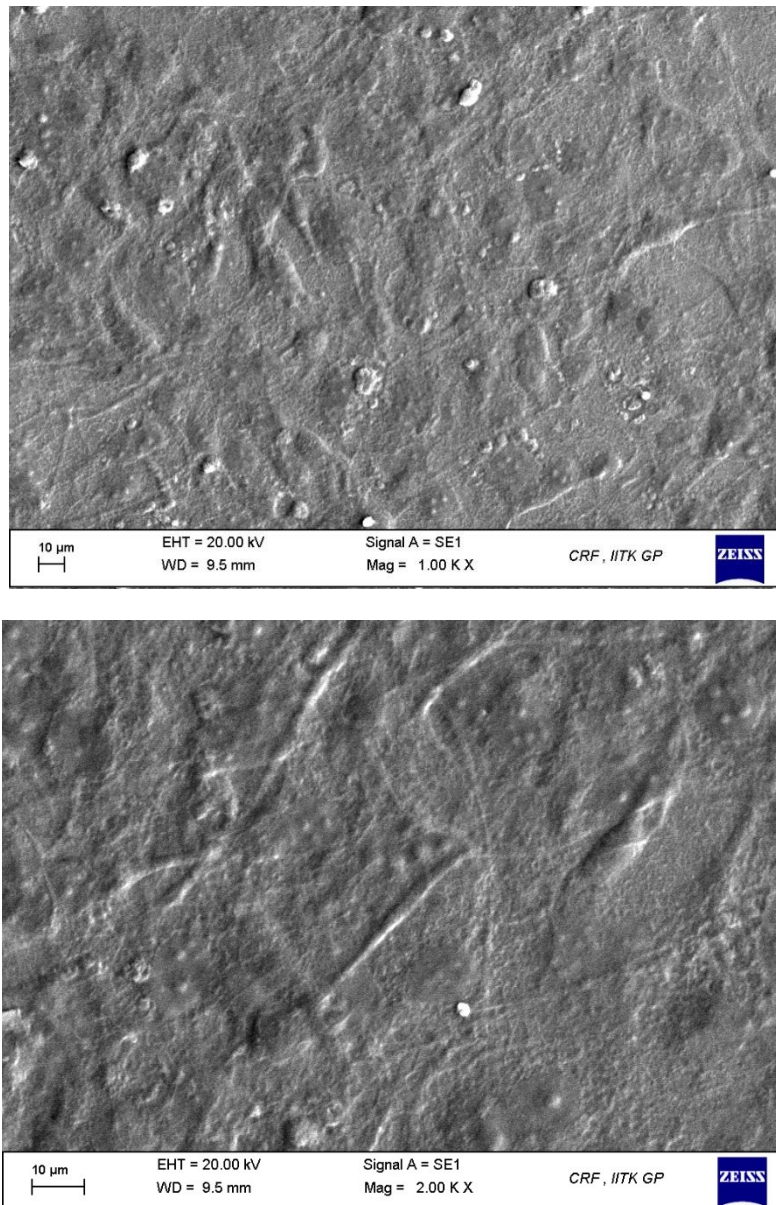


Fig 4(a, b): SEM images of Ni-Cu-P coated surface as prepared

Viewing Figure 4(a), the coatings appear to be flat with distribution of nodules⁴ on a moderate zoom. However, on closer look, in Figure 4(b) dense nodular morphology is evident. The higher nucleation rate during the deposition process is responsible for this nodular morphology.

Such a structure often offers a better heat transfer rate⁴⁶ and friction performance due to its self-lubricating nature⁴

7. CONCLUSION

- I. Synthesis of a suitable coating material on the surface of mild steel AISI 1040 has been performed.
- II. Electroless Coating Technique has been used for coating the mild steel surface.
- III. An heat transfer analysis experiment is being proposed using the coated material.
- IV. SEM images reveals the structural and morphological state of the coating.

8. FUTURE SCOPE OF WORK

- I. Detailed experimental study of analyzing heat transfer using electroless Ni-P-Cu coated material

- II. Further characterization of the coated mild steel and its detailed analysis.

- III. Studying the anti-corrosion and tribological properties of coating material.

- IV. Synthesis of different other coating composites/alloy coating for the application of heat transfer and a comparative studies of them.

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