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ELECTROCONDUCTIVITY PROFILES ON SPRAY DRYING: FEASIBILITY STUDY ON REDUCING FOULING DEPOSIT ON BOROSILICATE DRYING CHAMBER SURFACE VIA ALTERNATING REPULSIVE CHARGES

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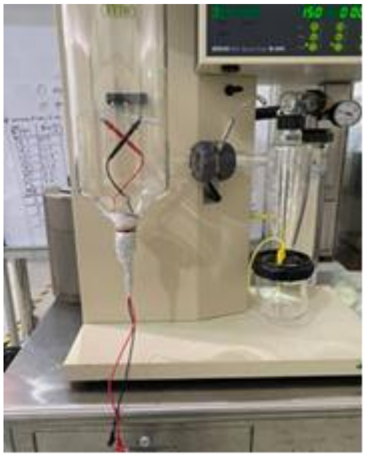
Graphical abstract



Abstract

Spray drying is a conventional technique for converting liquids into powders, involving preparation, homogenization, atomization, dispersion, and drying. However, electrostatic charges on the drying chamber walls and powder particles often cause adhesion and buildup, reducing process efficiency and cleanliness. This study aims to identify the types of electrical charges on powder particles contributing to impurity formation and to reduce such deposits by introducing alternating repulsive charges based on the dominant charge polarity. A total of 1,200 ml of full cream milk was subjected to spray drying, and the powder charge profile was measured using a multimeter to determine polarity in three replications. A system modeled after a Dual Output DC Power Supply applied repulsive charges through aluminum foil on the inner surface of a borosilicate chamber, generating 1140 Coulomb (C) of repulsive charge for each replication (Profiles 1–3, n = 3). The resulting electric charges were $5.0\times10^{-5} \pm 1.73$ C, $4.0\times10^{-5} \pm 1.73$ C, and $4.0\times10^{-5} \pm 1.73$ C of positive polarity ($p>0.05$). Comparisons of powder weight collected with and without repulsive charge application were 0.204 ± 0.082 g and 0.254 ± 0.080 g, respectively. Although powder weight decreased with repulsive charge, the difference was not statistically significant ($p>0.05$). These findings indicate that alternating repulsive charges have limited effectiveness in minimizing impurity deposits or enhancing spray drying efficiency, likely due to complex interactions involving charge behavior, temperature, and humidity. Future work should explore detailed models incorporating particle size, shape, and electroconductivity to better understand fouling mechanisms.

Keywords: Spray drying; yield, fouling deposit, alternating repulsive charges, electroconductivity; electric current

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Abstrak

Pengeringan semburan merupakan teknik konvensional untuk menukar cecair kepada serbuk, melibatkan proses penyediaan, homogenisasi, penyemburan, penyebaran dan pengeringan. Namun begitu, cas elektrostatik pada dinding ruang pengering dan zarah serbuk sering menyebabkan lekatan dan pembentukan mendapan, sekali gus mengurangkan kecekapan serta kebersihan proses. Kajian ini bertujuan mengenal pasti jenis cas elektrik pada zarah serbuk yang menyumbang kepada pembentukan kekotoran serta mengurangkan mendapan tersebut melalui penjanaan cas tolakan berselang-seli berdasarkan jenis cas dominan yang dikenal pasti. Sebanyak 1,200 ml susu penuh krim telah digunakan dalam proses pengeringan semburan, dan profil cas serbuk diukur menggunakan multimeter bagi menentukan polariti melalui tiga ulangan. Sistem yang diilhamkan daripada Dual Output DC Power Supply telah digunakan dengan meletakkan kerajang aluminium pada permukaan dalam borosilikat, menghasilkan cas tolakan sebanyak 1140 Coulomb (C) bagi setiap ulangan (Profil 1–3, n=3). Nilai cas elektrik yang diperoleh ialah $5.0\times10^{-5} \pm 1.73$ C, $4.0\times10^{-5} \pm 1.73$ C dan $4.0\times10^{-5} \pm 1.73$ C dengan polariti positif ($p>0.05$). Perbandingan berat serbuk yang dikumpul menunjukkan 0.204 ± 0.082 g dengan aplikasi cas tolakan dan 0.254 ± 0.080 g tanpa aplikasi. Walaupun terdapat pengurangan berat serbuk dengan cas tolakan, perbezaannya tidak signifikan secara statistik ($p>0.05$). Dapatan ini menunjukkan bahawa penggunaan cas tolakan berselang-seli mempunyai kesan terhad dalam mengurangkan mendapan kekotoran atau meningkatkan kecekapan pengeringan semburan, kemungkinan disebabkan interaksi kompleks antara cas, suhu dan kelembapan. Kajian lanjutan disaran untuk menilai model terperinci melibatkan saiz, bentuk dan kekonduksian zarah bagi memahami mekanisme fouling dengan lebih mendalam.

Kata kunci: Pengeringan semburan, keberhasilan, deposit kekotoran, cas tolakan bergilir; elektrokonduktiviti, arus elektrik

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1.0 INTRODUCTION

Fouling is characterized by the accumulation of unwanted deposits on the surfaces of heat exchangers. The relationship between the characteristics of the foulant and the structure, physicochemical properties, transport behavior, and performance of ion-exchange membranes in an electric field is examined through experimental data (such as ion exchange capacity, water content, conductivity, diffusion permeability, limiting current density, water splitting, electroconvection, etc.) and contemporary mathematical models [1]. Despite the various types of fouling, several stages can be distinguished: initiation, foulant transport, deposit adhesion, material transport from the surface, and aging of the deposit [2]. The term "fouling" generally refers to any type of fouling deposit material on the heat transfer surface. The nature of the deposit is highly dependent on the composition of the fluid treated by the exchanger. The fluid itself can be the source of the deposit, through organic decomposition under favourable temperature and pressure conditions. Fouling agents, which can be organic or inorganic substances, usually have poor thermal conductivity compared to the conductivity of metal walls, which results in a decrease in heat transfer rates [3]. However, fouling can also originate from solid or semi-solid materials suspended in the fluid [4].

The development of a fouling layer reduces the rate of heat transfer due to an increase in heat transfer resistance [5]. The impurity factor increases the required heat transfer area, which adds additional production costs. With less efficient heat exchangers, the economic cost of pollution is related to excessive fuel consumption, lost production, and maintenance or cleaning [6]. Fouling layers are often encountered in membrane separation and heat transfer operations in the food sector. This is because the conditions at the surface in such operations are known to promote transformation in foodstuffs: in membranes, the concentration of rejected species at the surface will promote gel formation or crystallization, while the capture of larger entities will lead to clogged pores [7]. The previous literature indicates that several factors influence the formation of dairy fouling, which can be categorized into three main groups: (i) product characteristics, (ii) process parameters, and (iii) surface properties [8]. Fouling is strongly influenced by food composition, and the inclusion of substances such as sweeteners, cocoa and hydrocolloids such as carrageenan in dairy products can alter the fouling behavior of certain surfaces. Indeed, it has been reported that during heat treatment, cocoa particles form large flocs which can provide a favorable environment for biofouling [9]. Foulants remain together on the membrane surface most likely due to the presence of physiochemical interactions, such as dispersion interactions between aqueous entities. This dispersion interaction is caused by the Van der Waals attraction between molecules across the water and is balanced by the electrostatic repulsion between the particles and the membrane surface due to the presence of surface charge [10].

This phenomenon presents a formidable technical challenge in the petrochemical industry, engines, aerosols and medical applications, membranes, and numerous operations within the particle technology industry, ranging from granulation to spray drying [11]. When spray drying technology is used to manufacture food products, powder handling problems can arise for some products due to application on equipment surfaces. Under some conditions, powder adheres to the drying surface, usually near the exit point, leading to possible clogging, downtime and product loss [12]. In the spray drying process, static charges may be generated in various ways: double-layer charging in the feed pipe, double-layer or induction charging at the spray nozzle and contact and friction charging on the spray cylinder walls and cyclone chamber [13].

The heat transfer between the wall and particles depends on the frequency of their contact, which is influenced by fluidized bed properties such as superficial gas velocity, bed height, particle size, and particle density, as well as the strength of interparticle forces. The thermal contact resistance is determined by the surface roughness of both the particles and the wall [14]. In addition, heat transfer creates local temperatures that promote phase changes, particularly solidification and rearrangement of proteins. Stickiness arises when these unwanted patterns of structured material stick and grow on surfaces [15]. A higher inlet temperature increases the moisture content of the powder and leads to the formation of larger particles [16] which can cause stickiness in spray drying. Additionally, spray drying results in a complex bipolar charging behaviour of the produced particles. Static charges can be generated during the spray drying process in different parts of the spray dryer in different mechanisms: in the feed pipe (double-layer charging), in the spray nozzle (double-layer or induction charging), and on the walls of the spray cylinder and the cyclone chamber (contact and charging friction) [17] which makes the powder from the spray drying process stick to the surface of the machine. Electrostatic-charged powder will adhere to surfaces, accumulate, and eventually cause blockages [18].

Electrostatic charging may occur at different locations within the spray drying process [13] and can cause impurity deposits in the drying chamber. Electrostatic repulsion can be used as an anti-stick measure. The advantages of charged membranes or particles are outlined, such as higher selectivity or retention or reduction of fouling phenomena. The repulsive force between the charged membrane surface and the charged foulant in the feed solution prevents foulant deposition on the membrane surface and reduces fouling [19]. Usually, it is appropriate to use a membrane that carries the same electrical charge as the foulant. For example, charged membranes have been primarily developed for the separation of charged solutes, such as proteins. The membrane charge should have the same sign as the charge on the product protein at a chosen pH value to increase the electrostatic exclusion of the product from the membrane pore [20]. Electrostatic repulsion between the membrane and foulants can help reduce membrane fouling caused by common foulants such as bacteria, polysaccharides, and natural organic matter (NOM), which typically have a negative surface charge [21]. Enhanced repulsion tends to result in higher repulsion of foulants and reduced membrane fouling [22]. Though electrostatic methods to reduce fouling exist, there is a gap in systematically exploring how alternating repulsive charges can specifically reduce fouling deposits on borosilicate drying chamber surfaces in spray drying operations. The objective of this study is to assess the feasibility of employing alternating repulsive charges to mitigate fouling deposits on the borosilicate drying chamber surface in spray drying. The research will explore how electroconductivity profiles affect fouling behavior and explore the operational impacts of applying electrostatic methods in spray drying systems.

2.0 METHODOLOGY

The main sample for this study is full cream milk produced by Dutch Lady Milk Industries Bhd. The milk used amounts to 1200 mL. The main equipment used was a borosilicate spray dryer at the Universiti Kebangsaan Malaysia (UKM) Food Pilot Plant. In addition, a branded digital multimeter (ANENG SZ304) was used and connected with a Meter Test probe, aluminum foil, and an iron mesh. Furthermore, an Agilent Technologies E3620A branded dual output DC Power Supply which is shown in Figure 1 was also used for this study.

Figure 1 Dual output DC power supply for supplying electroconductivity charges prior to profiling measurement

Spray Drying Operation

The operation of a spray dryer involves several steps taken to achieve the desired result. The inlet temperature was set at 150 °C, and the blower and heater were turned on to reach the pre-set temperature. The airflow rate was also set at around 54 m³/hour to support the drying process. The sample used was 200 mL of milk and after weighing the milk to calculate its density, the feeding tube was inserted into a container containing 200 mL of milk. The pump switch was turned on once the heater temperature reached about 150 °C. The pump speed was also set to approximately 335 ml/hour to ensure proper fluid flow. After the spray drying process was completed, the feeding tube was removed from the milk liquid container and inserted into the container containing water. Then, the spray dryer switch was turned off. The heater switch is turned off, and when the heater reaches 100 °C, the blower switch and compressor switch are also turned off. Finally, the pump switch was turned off to complete the entire spray dryer operation [22]. With this, the spray dryer operation is carried out effectively.

Charge Measurement on Fouling Deposits in the Spray Dryer

First, red and black Meter Test probes were connected to the digital multimeter. The Meter Test probes were placed on the wire mesh grid located in the drying chamber, as shown in Figure 2.

Figure 2 Preparation setup for the charges profiling of spray drying

Then, electric current readings were taken every 5 minutes using a digital multimeter during the spray drying operation for 50 minutes, along with the polarity readings, either positive (+) or negative (-). This process was carried out three times for each chamber that had fouling deposits. To analyse the charge profile on each drying chamber containing fouling deposits, the electric current values obtained from the digital multimeter were recorded.

Charge Profile Analysis on Fouling Deposits in Spray Dryer

The next step was to calculate the charge value (Q) using the recorded electric current (μA) data, applying the formula Q = It, where Q represents the electric charge (C), I is the electric current (A), and t is the duration time (s). This is because one ampere is equal to 1 Coulomb (C) passing a point in one second. Next, the obtained charge value is recorded from the calculation, and it is identified whether the dominant charge is positive or negative in the drying chamber. The trend of the electric charge values for each replication is presented in the form of a graph, and the calculated electric charges are statistically analysed to identify at which minute the electric charge experiences a spike.

Electric Field Operation

Due to the lack of studies on this operation concerning impurity deposits, modifications were made to the borosilicate surface of the spray dryer for this operation. First, aluminum foil was connected to the Test Meter probe to mimic the operation of the electric field on the borosilicate surface. Next, a Dual Output DC Power Supply that could supply electric current to the aluminum foil was installed and connected to a stable power supply as shown in Figure 3.

Figure 3 Spray dryer set up for electric field profile charges operation

Subsequently, the Dual Output DC Power Supply was turned on, and the spray drying operation was carried out simultaneously, with the electric current supplied through the Dual Output DC Power Supply set to the maximum value and the same polarity. Impurity deposits were monitored until the spray drying process was completed. After that, the aluminum foil that was subjected to electric current through the Dual Output DC Power Supply, as well as the aluminum foil without electric current (control), were removed from the drying chamber. For each replication, an electric current of 0.38A was consistently channeled through the aluminum foil, where a positive polarity electric charge of 1140 C was calculated using the formula Q = It (Q: electric charge (C), I: electric current (A), t: time (s)) suitable for the spray dryer operation. This is because if the electric current supplied exceeds 0.38A, the Dual Output DC Power Supply will be overloaded and could be damaged. Furthermore, electric charge profiling was not performed on the aluminum foil due to equipment constraints, focusing instead on the reduction of fouling deposits with and without the application of electric current by evaluating the weight of the powder in both conditions and the percentage reduction of fouling deposits. This operation was repeated three times (n = 3). The next step in the experiment is to measure the weight of the powder collected from each replication on the aluminum foil that was subjected to electric current through the Agilent Technologies E3620A Dual Output DC Power Supply, as well as on the aluminum foil that was not subjected to electric current (control). Subsequently, the percentage reduction in fouling deposits for each replication was calculated using Equation 1 below.

Weight of deposit (%) = (Weight of aluminum foil that was subjected to electric current (g)-Weight of aluminum foil that was not subjected to electric current (g))/(Weight of aluminum foil that was subjected to electric current (g))×100 (Equation 1)

Analysis of Fouling Deposit Reduction in the Drying Chamber

Results are given as mean values ± standard deviation from measurements of three replicates (n = 3). Statistical analysis data can be obtained from Minitab statistical software (Version 22.0, Minitab Inc., United States). One-way ANOVA was then performed to compare the mean values obtained. Tukey's test is performed to examine any significant differences between mean values at each confidence level $p<0.05$. In addition, a t-test is also performed to compare two different factors at a significant level of 95% ($p<0.05$).

3.0 RESULTS AND DISCUSSION

Charge Profile Analysis on Fouling Deposits in Spray Dryer

In this study, charge polarity profiling analysis was conducted by measuring the electric current value every 5 minutes. This current value was recorded on a digital multimeter (ANENG SZ304) which was connected to the iron net where fouling deposits from the sample milk were present. To determine the stability of the measured electrical charge, an electric charges vs exposure time analysis was performed based on the data obtained from each replication (n = 3). Figure 4 shows the graph of electric charge vs time from charge Profile 1. Based on Figure 4, the electric charge value initially decreases and then increases, but by the 30th minute, it becomes progressively stable throughout the spray drying operation. The electric charge value calculated from the electric current value in the first analysis is positive.

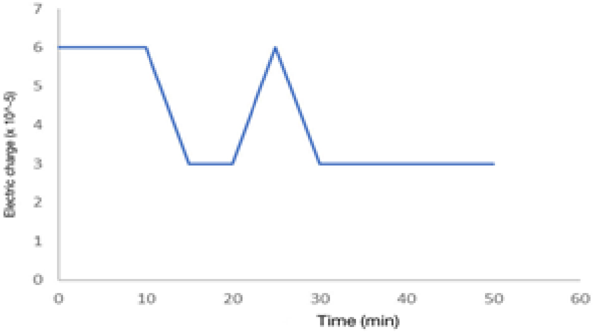

Figure 4 Kinetic profile electric charge for Profile 1 (+ve) charges (C)

Figure 5 displays the electric charge kinetics for charge Profile 2, where the electric charge value increases but remains unstable in the first minute. However, from the 40th minute onwards, the electric charge value becomes consistent until the spray drying operation ends. For Figure 6 which represents the electric charge kinetic vs time for Profile 3, the charge value increases and remains consistent until the 30th minute. After that, it fluctuates between increasing and decreasing but remains constant until the spray drying operation ends. The profiling of charges showed that the values of electric charges with positive polarity were unstable and inconsistent until the spray-drying operation of the milk sample was nearly complete. This means that the amount of electric charge from the measured electric current in the system remained stable over time.

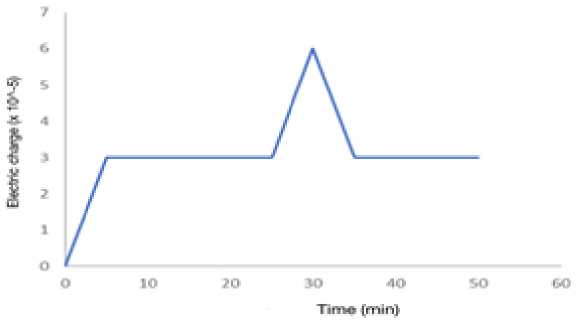

Figure 5 Kinetic profile electric charge for Profile 2 (+ve) charges (C)

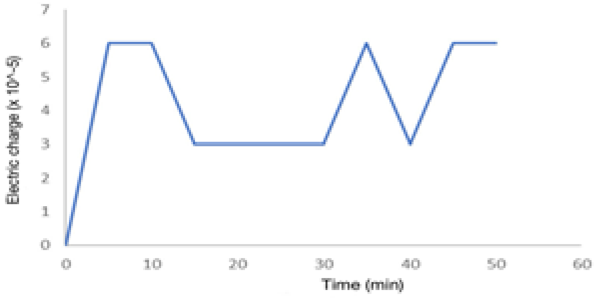

Figure 6 Kinetic profile electric charge for Profile 3 (+ve) charges (C)

According to [23], the current may be constant over time, oscillate with a constant frequency (AC, or alternating current), or vary over time. This is because the study used the same type of milk sample and the same spray drying parameters for each replication. However, each electric charge value obtained was positive, which aligns with the findings of [25] who reported that all dried milk particles acquired a positive polarity charge (+) as far as it formed on free electrons easily transferred to an electric conductor. Additionally, the electric charge values obtained from the electric current values also became stable over time during the 50-minute spray drying operation. Electric charge is a property of particles that manifests through electrostatic interactions. These electrostatic interactions occur between charged particles at a distance [26]. Static electricity is an imbalance of electric charges within or on the surface of a material. The charge remains until it can move using an electric current or electrical discharge [27].

Figure 7 shows a comparison between the kinetics of electric charge values without samples and with samples throughout the 50-minute spray drying operation. Charge electricity is obtained using a formula from the measured electric current value data throughout the operation. Based on Figure 7, charge Profile 1 and charge Profile 2 show an increase in electric charge at the 5th minute and maintain a high charge value until the 25th minute. Profile 2 charges then show fluctuations before becoming stable. Profile 3 also increased but with a lower value compared to charge Profiles 1 and 2 and has the same down and up pattern at the same time but with value a lower value. The current charge value of the control refers to the value of the electric charge that does not have factors that affect the value because there was no sample used during the 50-minute spray drying operation. The value of the electric charge during the control does not show any changes throughout the spray drying operation. This indicates that there were no electrical charges on the drying chamber during control conditions and the use of samples affected the charges and current values.

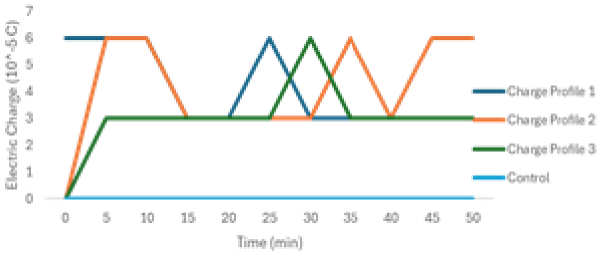

Figure 7 Kinetic profile of electric charge (C) throughout the operation for the control and with the sample electricity of the drying chamber

The graph also shows that after the 30th minute, the electric charge value with the sample becomes stable in the drying chamber. One-way ANOVA analysis was performed on all three charge profiles. According to Figure 8 which is a one-way ANOVA graph, there is no significant difference (p>0.05) in the electric charge carrying polarity positive over time during the spray drying operation. This is supported by the overlapping 95% confidence intervals and the same group letter 'a' which was assigned to most levels, indicating that any differences were not statistically significant. The trend on the graph shows that the electric charge was not consistent within the first 50 minutes of the spray drying operation. This indicates that the charging current reaches a stable value more quickly when the temperature and electric field are higher [26]. Therefore, the charge can maintain a relatively balanced state, remain trapped for a long time, or have a low migration speed [28].

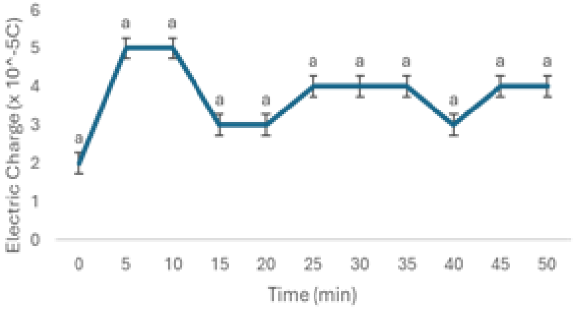

Figure 8 Kinetic profile of electric charge value data (C) against time throughout the spray drying operation (50 minutes)

Table 1 shows the value of the electric charge surge (positive charge) which has no significant effect (*p*>0.05) throughout the dry spraying operation period. The electric charge value was obtained from the electric current value measured during charge profiling. As the temperature increases, the initial current becomes larger and drops faster. This is because high temperatures promote the emergence of high-energy electrons and increase their free passage [29]. Therefore, very low or high temperatures, with low humidity, will increase the accumulation of electrostatic charges as they are generated [30]. Furthermore, almost all particles in the air have a positive charge, while negative ions have a negative charge. Hot or cold air forced through the work of most central heating and air conditioning systems provides friction that results in the loss of nearly all negative ions and draws most of the positive ions out of the air as well. Air with few positive ions and almost no negative ions is forced out through the space or hole [31].

Table 1 Spiking of electric charge (positive charge) along the kinetic profile of the electric charge in the drying chamber

Minute	**Electric +ve Charges (×10^{-5} C)**
5	5.0 ± 1.73^{a}
25	4.0 ± 1.73^{a}
45	4.0 ± 1.73^{a}

Values show mean ± standard deviation (*n* = 3). ^{a}The same letters indicate non-significant differences (*p*>0.05) in each column

Analysis of Fouling Deposit Reduction in the Drying Chamber

Table 2 shows the data for the total weight of milk powder with and without the application of electric current from the Dual Output DC Power Supply on the aluminum foil during the spray drying operation. For each replication (*n* = 3), an electric current of 0.38A was consistently applied through the aluminum foil, with a positive polarity charge value of 1140 C according to the formula Q = It (Q: electric charge (C), I: electric current (A), t: time (s)) which can be delivered according to the suitability of the spray dryer operation.

For each replication from Table 2, the powder weight value of the milk sample obtained from the control aluminum foil and the aluminum foil given an electric current for the control and the aluminum foil given the electric current has a difference where the weight of the powder in the control aluminum foil is lower than the weight of the powder on aluminum foil given an electric current. According to the t-test statistical analysis, the weight of the powder on the control aluminum foil and aluminum foil showed that it did not have a significant effect (*p*>0.05). This shows that the electric current carrying the same charge polarity does not affect the reduction of the powder in the aluminum foil due to the electrostatic repulsion produced. According to the study methodology, the percentage reduction of impurity deposits on the aluminum foil in the drying chamber has also been calculated and stated in Table 3 based on Equation 1.

Table 2 Data distribution of milk powder weight with and without providing electric current of dual output power supply on aluminum foil

Type of treatment	**Type of sample**	
	Control (g)	**Aluminum foil with Electric Current (g)**
	Weight of powder	**Weight of powder**
	0.254 ± 0.080^{a}	0.204 ± 0.082^{a}

Values show mean ± standard deviation (*n* = 3). ^{a}The same letters indicate non-significant differences (*p*>0.05) in each column

Fouling occurs when there is electrostatic attraction, while electrostatic repulsion results in antifouling. In cases where the surface has uncharged fouling, it generally occurs due to the absence of electrostatic interaction [32]. Electrostatic charges are prevented from escaping and forming electrostatic accumulation on the surface due to high electrical resistance. This can indicate a high voltage and low current [33]. Table 3 shows the data distribution on milk powder weight percentage with and without providing electric current through the dual output power supply on aluminum foil during the spray drying operation.

According to Table 3, the data shows the percentage reduction in powder weight under the condition of aluminum foil given electric current and the control is that this difference is not statistically significant (*p*>0.05). According to [34], this principle can resist impurities through electrostatic repulsion. However, this approach fundamentally does not improve antifouling. This is because the particles produced are usually combined with small particle sizes, which may lead to electrostatic problems [12]. Furthermore, inorganic materials such as aluminum foil generally have a higher dielectric constant compared to polymeric materials found in milk solutions. Intrinsically it contains ions and polar groups that contribute to its high dielectric constant. The mechanism that contributes to the dielectric properties is the interaction of the electric field with electronic polarization, atoms and dipoles [35]. This high dielectric constant means that the aluminum foil causes the induced polarization in the aluminum to neutralize or reduce the effective repulsive force between charged particles.

Table 3 Data distribution of milk powder weight percent with and without providing electric current through dual output power supply on aluminum foil

Type of treatment	Type of sample	
	Control (g)	Aluminum Foil with Electric Current (g)
	Percentage of milk powder weight	Percentage of milk powder weight
	20.6 ± 11.9%^{a}	16.4 ± 11.4%^{a}

Values show mean ± standard deviation (*n* = 3). ^{a}The same letters indicate non-significant differences (*p*>0.05) in each column

In addition, several other factors contribute to the fouling that often occurs on the dry spraying surface of slime from the electrical composition of the dry particles. According to [36], the time-dependent properties of glass transition-related cohesion for amorphous sucrose, maltose, glucose, galactose and fructose powders were studied. Cohesion is related to the combined effects of temperature and moisture rather than individual temperature, water activity or powder moisture content. The interaction analysis showed that strong electrostatic repulsion, rather than steric repulsion, is the primary factor for ensuring dispersibility in the spray dryer system [37].

The study revealed that the mechanism for sticking, sticky and flaking of amorphous sugar-based dairy products is through the temperature change of the phase of amorphous sugar from glass to rubber (T_g: glass transition temperature) and is likely to exceed the glass transition temperature (T_c: crystallization temperature) during the temperature dry spray operation which usually exceeds 150 °C. Milk fouling is also determined by a range of parameters including milk properties such as conformation or protein concentration, calcium concentration, pH, ionic strength, fluid dynamics such as flow rate and heat exchanger geometry, contact surface characteristics, for example, surface-free energy, composition and finishing, and process conditions, including fluid and surface temperature profiles [38]. The performance of fouled ion-exchange membranes (IEMs) in an electric field, such as during electrodialysis processes, is primarily influenced by changes in electrical resistance, the balance between hydrophilic and hydrophobic properties, surface roughness, and the distribution and morphology of fouling material on the membrane surface [1]. It is essential to enhance existing mathematical models for future studies and develop new ones that more thoroughly account for the interactions between materials used to make membranes, while also considering the unique characteristics of liquid media in the food industry. This includes the ability to alter the structure and electrical charge in response to changes in the pH of the environment [39].

4.0 CONCLUSION

Two parallel analyses were conducted in alignment with the study's objectives. The first analysis measured the electric current responsible for carrying the charge on powder particles that form fouling deposits in the drying chamber. The results confirmed that the milk powder particles carried a positive (+) charge. The second analysis evaluated the effectiveness of charge repulsion. Although a reduction in fouling deposits was observed in the borosilicate spray drying chamber due to the presence of a dominant positive charge, the induction of electric currents with positive polarity did not significantly enhance charge repulsion. If the results had shown a significant impact, alternating repulsive charges could be considered as a potential method to mitigate fouling in spray drying chambers. Furthermore, this study provides valuable insights into the nature of electric charge on milk powder particles and the role of charge repulsion in minimizing fouling deposits. The findings suggest that other factors, beyond alternating repulsive charges, may also contribute to the reduction of fouling. This study adds to the existing knowledge on improving spray drying efficiency in the food industry, and future research incorporating replication is recommended to enhance the accuracy of electroconductivity charge measurements. Furthermore, the inclusion of replication in subsequent investigations is expected to yield more accurate data, particularly concerning electroconductivity charge measurements.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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