Article

Drone Application for Spraying Disinfection Liquid Fighting against Covid-19 Pandemic – Theoretic Approach

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Abstract: The Covid-19 pandemic caused very serious problems almost to the whole world, so every opportunity must be considered to improve the situation. Decontamination carried out from the air can also be considered for surface clearance of larger areas, so the possibility of this application should also be investigated regarding pandemic. There are many examples of the use of drones for disinfection to improve the epidemic situation, but good practices, as well as factors influencing the effectiveness, have not yet been identified. In the case of using drone for disinfections during a pandemic, based on the reports, we can clearly discover the adapted use of agricultural drones. In this paper, the authors perform calculations with different values of flight speed (10 to 50 km/h), flight altitude (1 to 5 m), and flow rate (1 to 5 l / min) to determine the possible amount of disinfectant fluid per unit area. The results show that by changing the parameters, the amount of disinfectant per unit area can be given within quite wide limits (30 - 0.24 g/m^2). Although the results raise many new questions it can help to identify adequate flight parameters depending on different disinfectant liquids.

Keywords: drone, Covid-19, pandemic, disinfection, surface coverage, effectiveness

1. Introduction

The In the last hundred years, a total of 6 epidemics have swept the world, including the latest epidemic caused by the crown virus. These epidemics have claimed the lives of more than 10 million people. At the end of World War I, in 1918, the Spanish flu caused a pandemic. On a scale of 1 to 5 showing the mortality rate of epidemics, this was classified as the most severe, category 5, as more than 2 percent of cases resulted in death. From January 1918 to December 1920, the Spanish flu infected just over a quarter of the world's population at that time, 500 million people. The death toll has been put at least 17 million, but pessimistic estimates put 50 or even 100 million people dead [1].

Almost exactly 100 years after Spanish flu we face the 6th pandemic, that caused by SARS-CoV-2 virus, commonly known as Covid-19. We are over 120 million infected people and dead toll passed 2.5 million, practically all of the World is affected [2]. To overcome the difficulties caused by pandemic we should count with all of possibilities potentially able to fight against this virus. Drones, as the most dynamically developing part of aviation can be a very special tool in the hand of experts fighting against this pandemic. We could hear about different applications, such as area monitoring [3-5], special logistic support [6-9] and even spraying disinfectant liquid [10, 11]. This latest application as well as previous ones has not been developed yet for pandemic case therefore we do not know the best or good practices even if we know some initiatives for developing it [12-14], so it would be fine to know better what parameters influences its effectiveness.

One of the main features of managing any kind of pandemic is that authorized organisations suffer from the lack of resources to manage the situation with optimized way. The situation can be the same as in case of disasters [15]. In case of pandemic we focus mainly on the overloaded work or insufficient capacity of hospitals, ambulances, and medical services however partner organisations as well as police, civil protection or even government agencies can fall also into insufficient service. Experts must focus on the higher effectiveness managing pandemic meaning that they should use any new tools, facilities or methods that could help to eliminate the lack of resources mentioned above. Authors examine the possibility of drone application for spraying disinfection liquid fighting against Covid-19 pandemic.

Smaller drones may be suitable for observation, while larger ones may even be used for agricultural spraying. The use of drones for agricultural purposes is currently the most dynamically developing application [16, 17], so the appropriate tools are available in almost all countries. Experiences have shown that the disinfectant is applied in the same way as spray liquid used in agriculture; flying above a given area at a specified altitude and speed with the set fluid flow, the disinfectant is delivered to the surface by means of a pump (Figure 1). The anchor points of good practice are determined by virologists, such as the amount of disinfectant required per unit area, in the case of concentrate the mix rate, the required degree of coverage, and perhaps the frequency of spraying in the same area.

(a) (b)

Figure 1. Agriculture drone (DJI Agras T16) using for disinfectant release test: (**a**) flight test at open area to calibrate the flight parameters and fluid flow; (**b**) footprint test in place where drone spray disinfection was required. Source: authors' archive.

Authors have found only one serious scientific work focusing on this topic. González-Jorge at al. made an operational study of drone spaying and its effectiveness [14]. This work made flights with one specific drone in three different areas and measured the coverage in three different flight altitude. Approach of this study is practical, focused on the operational use of drone giving specific examples. In the present study authors give a theoretical approach to point at the maximum capability of using drone in disinfection missions. As we see at the discussion results of these studies are not far from each other however the practice still have potential to perform with higher effectiveness.

The manuscript is organized as follows: Section 2 shows the Material and Methods part, where presented both the requirements of the effective disinfectant coverage and the parameters influencing the effectiveness. For the calculation a 3D matrix was created in which the optimal surface coverage of disinfectant was presented by the influencing parameters that is flight speed, flight altitude and fluid flow. Section 3 depicts the results of the calculations in tables and with 3D function. Section 4 focuses on the discussion and the topics that is suggested for further research.

2. Materials and Methods

2.1. Adequacy of drone spraying

Immediate adaptation of the agricultural application seems simple and effective, but in order to increase future efficiency, it is worthwhile to develop a protocol for the procedure. According to the published information, the size of the disinfected area varies, depending on the quality of the spraying and the performance of the drone used. It varied between 10 and 40 hectares per day [10, 11]. This value is of the same order of magnitude as in agricultural applications. We can also find data on the disinfectant used, mostly a chlorine-containing chemical with a mixing ratio of 1 to 3% [10, 11], but we can also find other substances like alcohol, bleach, peroxide whose composition is not known exactly [18]. There are platforms where substances like bleach and alcohol is also suggested officially as an option for decontamination [19, 20]. Based on the above, it can be seen that the composition of the disinfectant fluids used is different, not uniformly defined.

Based on reports and published evaluations there are no direct data about the value of surface coverage however, by consultation with virologist, it is not the amount of disinfectant applied per unit area that is important, but the ability to form a full coverage by a thin or film-like layer, if possible. Complete coverage of the surface can be achieved by various methods, e.g. it can even be realized by wiping, which really creates a very thin film layer that thickness can be expressed by nanometers [21, 22]. Cleaning and disinfection for smaller rooms, e.g. for office the method of wiping with disinfectant liquid is also recommended by the authorities [20], therefore the effectiveness of this method is accepted by practice as appropriate for even in case of Covid-19.

Creating a cohesive film layer by using drone spraying that means the free falling of droplets, is obviously a more complex process than using the wiping method. When spraying with a drone we must take into account the number of drops falling on the unit surface, the size of the droplets, the characteristics of the liquid (e.g. surface tension), the surface roughness, the flight parameters, and the effect of the wind. The present study focuses on identifying the cornerstones of good practice, so the authors examine the effect of changes in flight parameters, assuming that other variables are ideal. That is, we assume that there is no wind that blows the droplets, and when the droplets come to the surface, they spread out so that they cover the entire surface. In this way, we can determine the theoretically achievable optima, which must be taken into account with a safety factor.

The behavior of thin liquid layers on the surface and the conditions of droplet dispersal have been studied by several authors, based on which it can be proved that the thickness of the film layer can be formed in nanometers dimension [23-28]. In the case of wiping, the thickness of the film layer is obviously thinner than when examining the spontaneous spreading of the droplets, so the results of the latter are also acceptable as a base of good practice for drone spraying. Based on the above, our task with drone spraying is to create a film layer at least as thick as can be formed by wiping. The thickness of the cohesive film layer that can be formed by wiping is influenced by a number of factors, e.g. the characteristics of the fluid, the degree of surface tension, the roughness and shape of the surface (Figure 2). In units of the molecular diameter of water is 0.317 nm. Depending on the literature, the thickness of the film layers can be even less than 50 nm [29] but the thickness reaching 100 nm can be considered quite general [23], so as a basis of good practice we accept that the film layer covering the surface must reach at least a thickness of 100 nm.

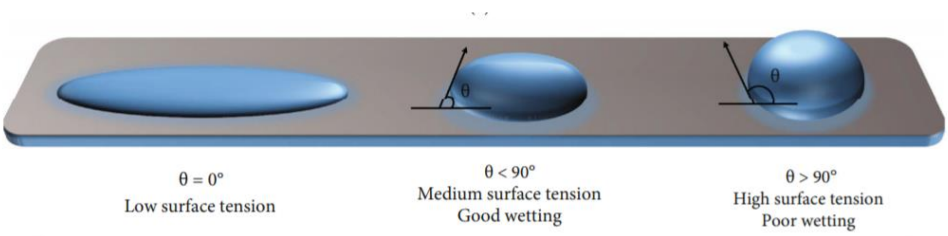

Figure 2. The wetting behavior of the droplet on the surface. θ is the contact angle between the droplet and the surface. High θ values means poor vetting (right), lower means good wetting (middle). In case of θ = 0 surface tension is very low (left) [30].

Based on the practice of agricultural spraying and the authors' own tests and experience, achieving full coverage is sometimes difficult to achieve. Although the droplet size of the disinfectant emitted by the nozzle is very small, usually less than 300 μm, the average droplet density at a flight altitude of 1.5 m can be less than 200 pcs/cm^2, and the surface coverage is sometimes only approx. 12%. Although this initial coverage ratio can be considered low, it should be taken into account that with the help of a surface tension reducing additive we can multiply the coverage ratio [24-28]. After the liquid has come to the surface, the droplets spread on the surface, reaching a multiple of their previous diameter size, losing their initial shape due to the surface tension reducing additive. With this spread, the individual droplets will hopefully come into contact to each other and can even provide a film-like, complete coverage of the surface. This is also confirmed by the practice of agricultural application, as partial cover is not allowed in order to prevent or stop the spread of infections.

As the flight altitude increases, the width of the sprayed surface increases too, but the rate of surface coverage shows a decreasing trend. At the recommended flight altitude for agricultural applications, the width of the effectively sprayed surface is approx. 7 m, but in case of precisions applications it reduces to 4.5 m [18]. Based on drone spraying experiments against Covid-19, Gonzalez-Jorge at al. recommended a flight altitude of 3 m [14]. This paper was found as the only one scientific study focusing on drone spraying application against Covid-19. In this study we can get a real flight tests data that is very useful and determined even the research focus of this paper too.

In this study, based on practical experience to date, we assume that different disinfectant fluids may be used, but the reasons for this are not investigated. However, different disinfectant fluids obviously also have different disinfectant effectiveness, so it is assumed that different amounts per unit area will need to be applied depending on the characteristics of the fluid. The required amount of different disinfectant fluid is determined by a specialist, a virologist, so the pilot of the drone must perform the spray task in such a way as to ensure the specified amount per unit area, taking into account the other influencing factors, especially the flight parameters.

2.2. Parameters influencing effectiveness

The emission of the drone is assumed to be point-like, and the spray angle of the nozzle is assumed to be 53 degrees, which is not far from agricultural practice. With these values, at low flight altitudes (≤ 5 m) we obtain a spreading width approximately as wide as the flight altitude, i.e. 1 m wide at a flight altitude of 1 m, and 5 m wide at flight altitude of 5 m high.

For spraying to a flat surface, two parameters related to flight and two disinfectants should be taken into account. In the case of flight, the flight speed and flight altitude, and in the case of disinfectant, the mixing ratio of the disinfectant concentrate and the amount of liquid sprayed by the drone. Maintaining the previous assumption, droplets falling to the surface spread out and result in complete or by virologist acceptable coverage.

1. The ratio of the components of an effective disinfectant must be determined by a virologist. This data is not directly related to flight parameters but indirectly influences those because the effectiveness of the disinfectant solution is certainly influenced by both the uniformity of the surface coverage and the amount of solution per unit area. Higher effectiveness requires less disinfectant solution per unit area and perhaps can even less the coverage than total.
2. The flight speed fundamentally determines the effectiveness of the spray application, so examining this is inevitable. It is logical that increasing the flight speed, the size of the disinfected area also increases, so in area size of view the goal is to achieve as high flight speed as possible. At the same time, however,

with other conditions unchanged (same flight altitude, same amount of emissions), higher flight speeds reduce the amount of disinfectant liquid per unit area. The speed can only be increased as long as the required amount of disinfectant on the surface can be satisfied. The flight speed is calculated with 5 different values, preferably in equal divisions. The lowest value is stated as approx. twice of the average pedestrian speed, the upper is the maximum value normally used for spraying in agriculture. Based on these values calculation used the flight speed of: 10 km/h - 20 km/h - 30 km/h - 40 km/h - 50 km/h.

3. The flight altitude also significantly affects effectiveness. It is logical that as the altitude increases, the size of the sprayed surface also increases, so the goal is to achieve the highest possible altitude in order to increase the effectiveness. As it mentioned at the flight speed above, the altitude cannot be increased arbitrarily, as the amount of disinfectant solution per unit area may reduce below the threshold required to achieve a sufficient disinfectant effect. The flight altitude is calculated with 5 different values, preferably in equal divisions, giving the minimum and maximum heights those effectively used for precision agriculture spraying at both the lower and upper values. Based on the above, the examined altitude values are: 1 m - 2 m - 3 m - 4 m - 5 m.
4. The amount of disinfectant liquid sprayed per unit time also plays an important role. A fundamental limitation of any settings is that the nozzles to be used have been optimized for the requirements of agricultural spraying. Thus, both the minimum and maximum fluid flow per minute are limited. Due to the dynamically spreading agricultural drone application, it is accepted that the scattering pattern with the formed nozzles is sufficiently uniform and in any case suitable for agricultural application. In order to increase the effectiveness - in the case of longer straight flight sections - the aim would be to maximize the liquid flow, because in this case, either the flight speed, the flight altitude, or both could be increased simultaneously. In line with the previous ones, the amount of liquid flow is determined with several different values for the calculations. At the lowest value with the minimum effective amount (1 l / min) assumed on previous practice, at the upper value with the maximum flow capacity of drone pump usually used on board (5 l / min - DJI Agras T16, TTA M6E-X). Based on the above, the examined fluid flow values are: 1 l/p - 2 l/p - 3 l/p - 4 l/p - 5 l/p.

It can be seen that the different elements determine the effectiveness together. Even if they can be physically independent of each other, yet they strongly influence each other.

2.3. Spray coverage 3D matrix for disinfectant effectiveness

To calculate with the above parameters, a 3D matrix was created containing 5 x 5 x 5 = 125 data, as it shown on Figure 3. In the case of test flights, we recommend that the number of flights should be significantly reduced by choosing the correct order of testing. If we are looking for an effective part of the above matrix, it is worth to begin with the flights with a presumably acceptable disinfectant effect, and then determining the further flight order accordingly, as long as the results serve the purposes of the research. Logically, it is obvious that all flights serve results, however, in order to reduce time and costs, flights that do not provide relevant results can be omitted.

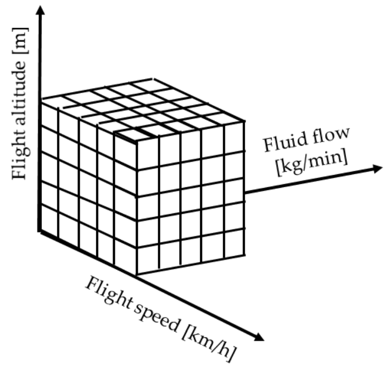

Figure 3. Spray coverage 3D matrix with 5 x 5 x 5 = 125 data for calculations. Flight speed, flight altitude and fluid flow are take into account.

The elements of the 3D matrix, that means the measured data, have 3 parameters, such as the flight speed, the flight altitude and the quantity of the emission during the unit time that is the liquid flow. We used the notation "V" for the series of speed values, so it has the form: V10 - V20 - V30 - V40 - V50. We used "H" to denote the series of altitude, so the form of the series is: H1 - H2 - H3 - H4 - H5, while we used "M" to denote the series of fluid flow, so as before, the form of the series is: M1 - M2 - M3 - M4 - M5. Based on the above, the element of the spatial matrix of the liquid flow of 1 l / p at a speed of 10 km / h at 1 m altitude is denoted by V10H1M1, while that of the element of the spatial matrix of the fluid flow of 4 l / p at a speed of 40 km / h at 3 m altitude is V40H3M4, as it shown at Figure 4. The measurement markings are visibly simple, the flight and liquid flow parameters associated with the data are easy to code and to decode.

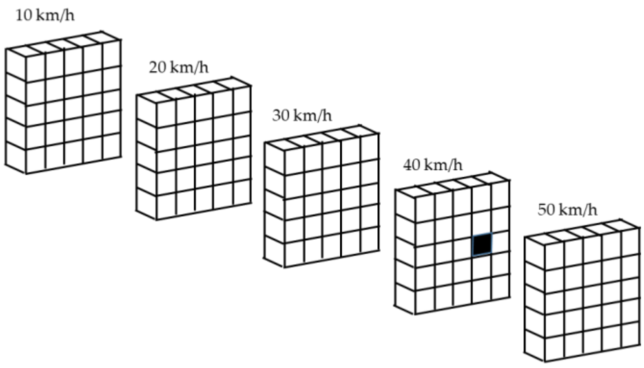

Figure 4. Speed series in the matrix. To find the location of V40H3M4 code is easy in the spray coverage 3D matrix.

Research goal is to determine whether the sprayed disinfectant is present on the surface in the right amount and with the right coverage and appropriate distribution. Based on this, matrix notations can have two evaluated values.

1. In the first case, when examining the sprayed liquid quantity, we can give the value of the coverage amount (quantitative assessment – g / m^2), or only that its effect is appropriate or not (qualitative assessment - Y / N).
2. In the other case, when determining the degree of coverage, we can do the same. You can specify the coverage ratio (quantitative rating - %) or just that the virologist considers it as acceptable or not (qualitative rating - Y / N).

Obviously, we can accept as flight protocols only those elements that both values are acceptable e.g. V30H2M4 - 12Y or V30H2M4 - YY (if 12 g / m^2) is acceptable to a person skilled in the pandemic). The former is more useful for virologists and experts, the latter is more useful for drone pilots performing flights.

3. Results

Matrix data were determined by correlating the disinfectant fluid value of unit area to the flight speed values those calculated as a function of flight altitude and fluid flow.

3.1. Results of 10 km / h flight speed

The optimum amount of disinfectant liquid per unit area, expressed in g / m² at a flight speed of 10 km / h, as a function of flight altitude and fluid flow per minute, with tabulated values and graphical representation as shown in Table 1.

Table 1. Surface coverage (g / m²) at flight speed of 10 km / h depending on flight altitude (1 – 5 m) and fluid flow (1 – 5 kg / min).

Fluid flow	**Flight altitude [m]**				
[kg / min]	**1**	**2**	**3**	**4**	**5**
5	30	15	10	7.5	6
4	24	12	8	6	4.8
3	18	9	6	4.5	3.6
2	12	6	4	3	2.4
1	6	3	2	1.5	1.2

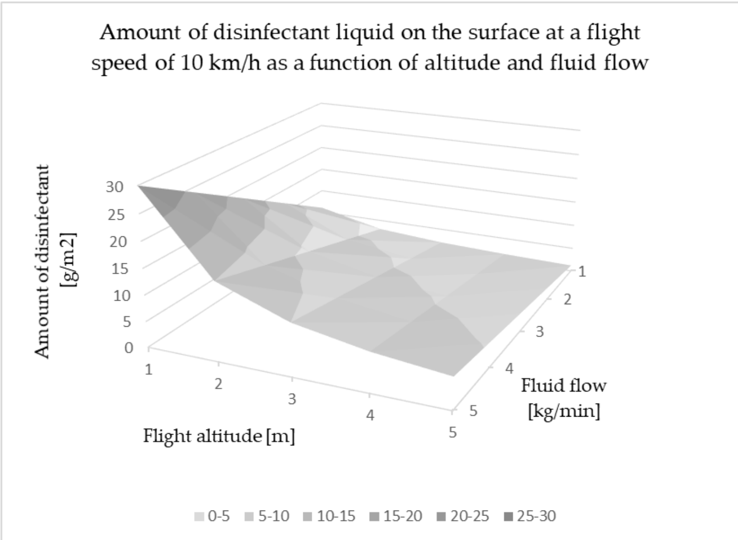

Figure 5. Function of surface coverage (g / m²) at flight speed of 10 km / h depending on flight altitude (1 – 5 m) and fluid flow (1 – 5 kg / min).

3.2. Results of 20 km/h flight speed

The optimum amount of disinfectant liquid per unit area, expressed in g / m² at a flight speed of 20 km / h, as a function of flight altitude and fluid flow per minute, with tabulated values and graphical representation.

Table 2. Surface coverage (g / m²) at flight speed of 20 km / h depending on flight altitude (1 – 5 m) and fluid flow (1 – 5 kg / min).

Fluid flow	**Flight altitude [m]**				
[kg / min]	**1**	**2**	**3**	**4**	**5**
5	15	7.5	5	3.75	3
4	12	6	4	3	2.4
3	9	4.5	3	2.25	1.8
2	6	3	2	1.5	1.2
1	3	1.5	1	0.75	0.6

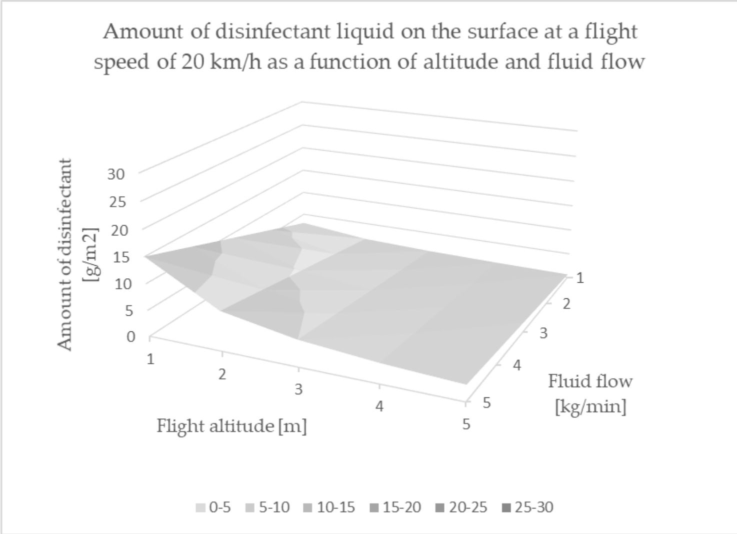

Figure 6. Function of surface coverage (g / m²) at flight speed of 20 km / h depending on flight altitude (1 – 5 m) and fluid flow (1 – 5 kg / min).

3.3. Results of 30 km / h flight speed

The optimum amount of disinfectant liquid per unit area, expressed in g / m2 at a flight speed of 30 km / h, as a function of flight altitude and fluid flow per minute, with tabulated values and graphical representation.

Table 3. Surface coverage (g / m²) at flight speed of 30 km / h depending on flight altitude (1 – 5 m) and fluid flow (1 – 5 kg / min).

Fluid flow	**Flight altitude [m]**				
[kg / min]	**1**	**2**	**3**	**4**	**5**
5	10	5	3.3	2.5	2
4	8	4	2.7	2	1.6
3	6	3	2	1.5	1.2
2	4	2	1.3	1	0.8
1	2	1	0.67	0.5	0.4

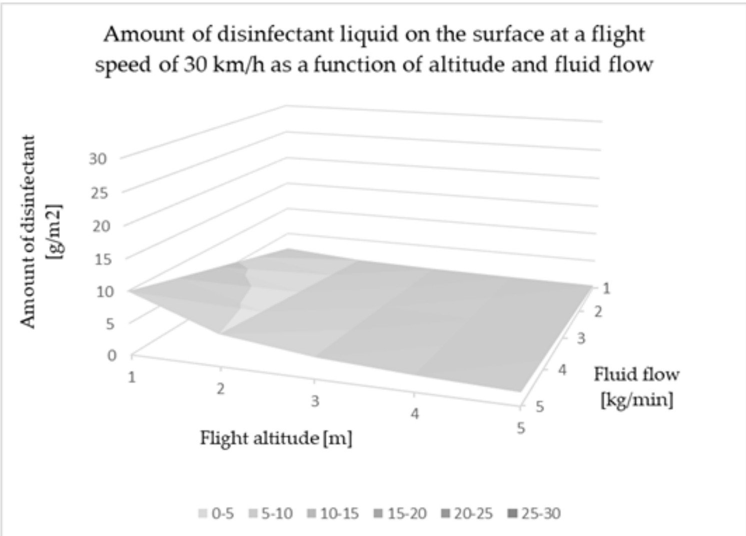

Figure 7. Function of surface coverage (g / m²) at flight speed of 30 km / h depending on flight altitude (1 – 5 m) and fluid flow (1 – 5 kg / min).

3.4. Results of 40 km/h flight speed

The optimum amount of disinfectant liquid per unit area, expressed in g / m2 at a flight speed of 40 km / h, as a function of flight altitude and fluid flow per minute, with tabulated values and graphical representation.

Table 4. Surface coverage (g / m²) at flight speed of 40 km / h depending on flight altitude (1 – 5 m) and fluid flow (1 – 5 kg / min).

Fluid flow	**Flight altitude [m]**				
[kg / min]	**1**	**2**	**3**	**4**	**5**
5	7.5	3.75	2.5	1.88	1.5
4	6	3	2	1.5	1.2
3	4.5	2.25	1.5	1.13	0.9
2	3	1.5	1	0.75	0.6
1	1.5	0.75	0.5	0.38	0.3

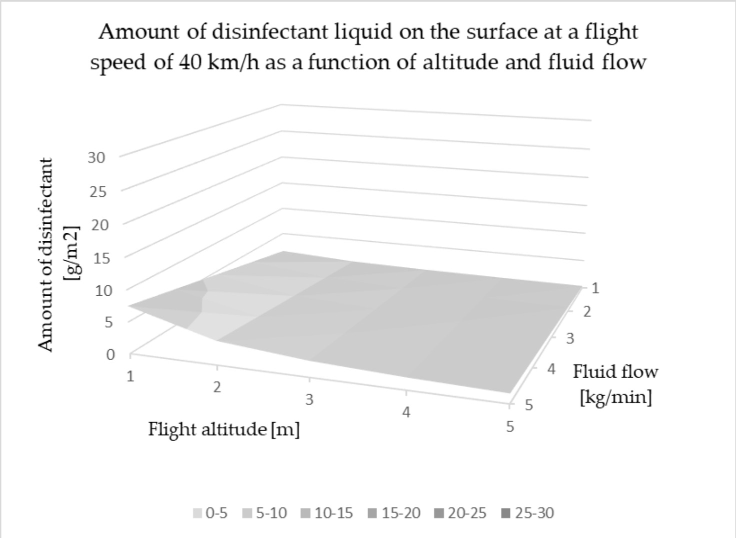

Figure 8. Function of surface coverage (g / m²) at flight speed of 40 km / h depending on flight altitude (1 – 5 m) and fluid flow (1 – 5 kg / min).

3.5. Results of 50 km / h flight speed

The optimum amount of disinfectant liquid per unit area, expressed in g / m² at a flight speed of 50 km / h, as a function of flight altitude and fluid flow per minute, with tabulated values and graphical representation.

Table 5. Surface coverage (g / m²) at flight speed of 50 km / h depending on flight altitude (1 – 5 m) and fluid flow (1 – 5 kg / min).

Fluid flow	**Flight altitude [m]**				
[kg / min]	**1**	**2**	**3**	**4**	**5**
5	6	3	2	1.5	1.2
4	4.8	2.4	1.6	1.2	0.96
3	3.6	1.8	1.2	0.9	0.72
2	2.4	1.2	0.8	0.6	0.48
1	1.2	0.6	0.4	0.3	0.24

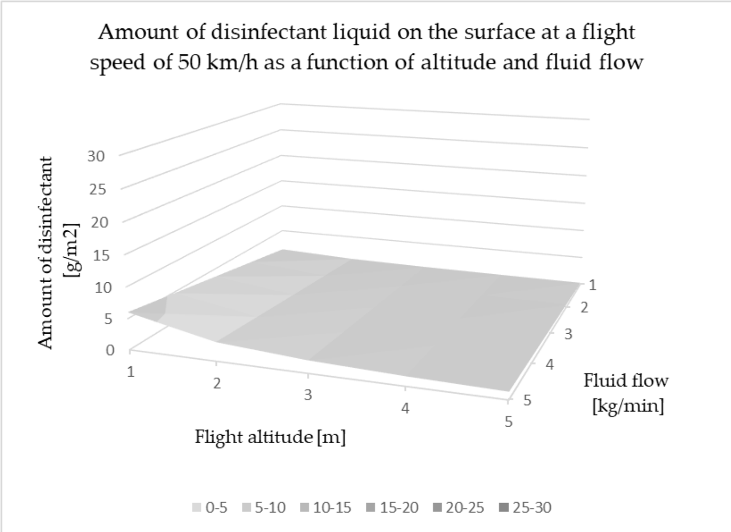

Figure 9. Function of surface coverage (g / m²) at flight speed of 50 km / h depending on flight altitude (1 – 5 m) and fluid flow (1 – 5 kg / min).

4. Discussion

From the values in the matrix, it can be seen that by changing the parameters, the surface volume of the disinfectant fluid varies within quite wide limits. The highest values are reached at low flight speed (10 km / h), low flight altitude (1 m) and high fluid flow (5 l / p) (30 g / m²). The lowest surface area value is achieved at higher flight speeds (50 km / h), higher flight altitudes (5 m) and low fluid flow (0.24 g / m²). Between the smallest and largest surface coverage, the difference is approx. 125 times! From this we can conclude that the drone pilot can change the amount of surface coverage in a rather wide spectrum by changing the flight parameters as well as the fluid flow. This allows different disinfectant fluids with different properties to be applied to the surface in an amount that already ensures the effective disinfection.

It can also be seen from the values of the matrix that a given amount of surface material can often be achieved with several parameters. For example 2 g/m² can be achieved with all speeds and heights as well as fluid flow (V10H3M1, V20H3M2, V40H3M4, V50H3M5 and 5 times in the Table 3).

To justify the effectiveness of drone application, the amount of disinfectant liquid on the surface must be converted to the thickness of the film-like layer covering the surface. The highest value, the liquid volume of 30 g / m², ideally means that the uniform film layer is 30 μm thick, while the lowest value, the liquid volume of 0.24 g / m², represents a thickness of 240 nm. It is natural that differences between the thicknesses, as well as between the masses is the same that is approx. 125 times.

It has already been proved above that a uniform film layer of almost any thickness, even a few nm thick, which is close to effective disinfection is sufficiently effective, but the thickness of 100 nm can surely be considered as acceptable based on the work of others [23, 29]. Based on this, in optimal case even the smallest value should be sufficiently effective on a smooth, even surface.

It is obvious that in nature we rarely find a smooth surface where with the given coverage, e.g. the 240 g / m² we can create the ideal, in this case a uniform film layer with a thickness of 240 nm. Due to the shape variations, waviness and roughness of the materials, we have reason to assume that the thickness of the film layer from droplets will not develop optimally. The purpose of drone spraying is that to make a smooth surface coverage of at least min. 100 nm thickness on all points of the surface. If drone spraying can provide this requirement on all points of the surface or at least in such a ratio that is acceptable by experts, the drone application is effective. For this, we have a safety margin of 2.4 times at the lowest value and 300 times at the highest. To determine the minimum level of safety factor, the authors propose further research.

With the data of surface coverage and the size of tank installed on board we can calculate even the area that can be sprayed. In case of 30 g / m^2 coverage with 10 liter tank capacity (e.g. TTA M6E-1) area of 333 m^2 can be disinfected, however with 0.24 g / m^2 coverage the area is more than 4 hectares (41,667 m^2) that seems excessive in practice view.

Mission time for optimal case can also be calculated. At the first case (speed = 10 km/h, altitude = 1 m) the total flight distance is 333 m and the flight time of the mission with one full tank takes 2 min (120 sec). At the last one (speed = 50 km / h, altitude = 5 m), with 0.24 g / m^2 coverage, the total flight distance is 8333 m, flight time takes 10 min (600 sec). Naturally all data is optimal and based on theoretical calculation.

There are some factors those can cause problems creating very thin layer, first is the evaporation. The question is that, how long time have to be the disinfectant in liquid phase on the surface. Practice show that after wiping the surface it becames dry again in a very short time. Water, as the most part of the chlorine based disinfectant, evaporate quickly depending on many factors, however the temperature and humidity is surely the most important factor of it. In case of high temperature and/or in low humidity the safety factor must be surely higher than in normal case. To determine the effect of evaporation, the authors propose further research.

Other problem is the wind that can move the small size droplets from the required space after release. Even if this can be a problem it can be supposed rotor wind of the drone is enough strong to force droplets touching the surface. Naturally the phenomena of spray drift is an existing problem therefore it is required to examine or adapt the experiences of precise agriculture.

Based on the above using drone for spraying disinfection liquid fighting against Covid-19 pandemic is a very good option however further researches and practical experiences required to base the best practice.

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