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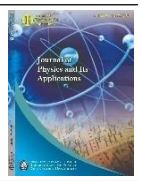

Effect of Temperature and Humidity on The Visibility of Mirage on The Runway of Sultan Iskandar Muda Airport, Aceh, Indonesia

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ABSTRACT

The relationship between temperature and humidity of air and visibility of mirage has been studied by observing mirage on the runway of Sultan Iskandar Muda International Airport (SIM) Aceh, Indonesia. Temperature and humidity data were obtained from BlangBintang Meteorology, Climatology and Geophysics Station's database, Aceh Besar, Aceh, Indonesia. It was observed that mirage has shown up from morning to afternoon, from 07.00 AMuntil 18.00 PM, even until sunset. Mirage is also still visible when the weather is cloudy or drizzling, but disappeared when heavy rain. The lowest and highest temperatures where the mirage can still be observed are 26.0^{0}C and 32.0^{0}C, respectively. Meanwhile, the lowest and highest air humidities where mirages can still be observed are 51.0% and 92.0%, respectively. Observation shows that changes in temperature and humidity in the runway environment greatly affect the appearance and visibility of mirages. When the air temperature is high and the humidity is low, the mirage appears with high visibility (very thick), so that it can be observed clearly visually. Conversely, when the temperature of air is low and the humidity is high, mirage appears with low visibility (very thin) or almost non-existent or completely gone.

1. Introduction

Mirage is an optical illusion caused by the effect of variations in the refractive index of fluid on the surface of an object due to changes in fluid temperature. Mirage can be observed in open or flat areas such as asphalt roads, deserts and seas. A very familiar mirage phenomenon is when the ray of light is almost parallel to the hot surface of the earth, the sky and objects on the horizon then appear to be reflected by the surface [1-2]. In general, mirage are formed when the surface temperature of land in a flat area such as the desert is higher than the temperature of the air layer above the surface of the land. In this case, the light undergoes refraction and total internal reflection (TIR), in the air layer and forms the image of an object called a mirage [3-7].

Effect of a mirage is easily known when an observer sees a celestial object at a certain height, the actual position of the object becomes lower due to refraction of light after propagation through the atmosphere with a refractive index gradient that gives rise to a curved light path [8-10]. Mirage is very interesting phenomenon because the length of the area experienced a very small change in temperature, but the radius of curvature of the light rays passing through the area could be very large [11]. Understanding on formation process of mirage is paramount importance, since it has many potential practical applications, such as the detection of heat waves generated by the absorption of light on solid objects by measuring the refractive index in liquids in contact with absorbing samples, atmospheric photography, ocean photography, measuring concentration variation in diffusion layer and its optical properties, etc [12-14]. Observation of a mirage depends on the distance between the observer and the object [12] and can only be observed on homogeneous media. In homogeneous fluids, light propagation is very dependent on refractive index, n. The refractive index of air, n is influenced by temperature, T, pressure, P, density, ρ and humidity, RH [9, 15-18]. If temperature is low, density increases, so the refractive index increases, conversely. The refractive index, n is expressed in the following equation:

$$n = 1 + \frac{77.6P}{T} x10^{-6} \quad (1)$$

temperature and pressure of air are related to density expressed in the following equation

$$n - 1 \propto \frac{P}{T} \quad (2)$$

because

$$n - 1 \propto \rho \quad (3)$$

and

$$\rho \propto \frac{P}{T} \quad (4)$$

Relative humidity (RH) represents the amount of water vapor in the air. High RH values indicate the amount of water vapor in the air is high [12]. The rate of evaporation of water in the air increases with increasing temperature. The temperature and humidity of the air are influenced by the season, where in the dry season, the general temperature is high and the humidity is low. However, during the rainy season, temperature drops and humidity becomes higher [18]. Thus, the appearance and visibility of a mirage is strongly influenced by changes in the refractive index of the air layer on the surface of the object, where the change in the refractive index of the air layer on the surface of the object is greatly influenced by temperature of the air and temperature of the object surface. Therefore, temperature and humidity are parameters that very important for observing mirage.

One place that can be used to easily observe a mirage is the airport runway. Therefore, mirage observations have been made at Sultan Iskandar Muda Airport (SIM). SIM Airport is the main airport in Aceh Province. Measurement of weather conditions in the airport runway environment is carried out by Meteorology, Climatology and Geophysics Station located in Iskandar Muda Airport. Data from the measurement of temperature and humidity at Meteorology, Climatology and Geophysics Stationcan be used to assess the visibility of mirage on SIM airport runway.

Previously it has been reported the influence of temperature and pressure of air on SIM Airport environment on the appearance and visibility of mirage where it is found that the appearance and visibility of mirage is strongly influenced by the temperature and pressure of the surrounding air. The lower the temperature, which causes the air density to increase so that the air pressure is higher, the thinner the mirage appears and the lowe the visibility of the mirage. Conversely, the higher the temperature, which results in decreased air density so the pressure is getting smaller, the thicker the mirage appears, the higher the visibility of mirage. Thus, the temperature profile and air pressure of runway environment can be known through mirage observations [20]. This study reports the relationship between temperature and humidity of the airport environment with visibility of mirages.

2. Methods

Observation of mirage visibility was carried out on SIM airport runway for 17 days in a period of time from May to September 2016. The observation methods and schedule are the same as the schedule outlined in detail in the previous report [20]. Observations were made for 12 hours every day starting at 07.00 AM in the morning until 18.00 PM in the afternoon. Observation of the visibility of a mirage is done by looking at and recording the time of its appearance, distribution and intensity (thickness) of the mirage.

Mirage observations are made at one end of the SIM airport runway as indicated by the white rectangle shown in Figure 1. The reference points for observations are selected at several distances indicated by zebra lines at the end of the airport runway as shown in Figure 1. Observer's position is about 100 m straight from the end of the runway. The position of the zebra lines is used as a reference in determining the appeareance and thickness of the mirage. The thickness of the mirage and its appearance position are expressed by the symbols A, B, C, D, and E. The mirage is said to be very thick (E) if the entire runway section in the white box in Figure 1 is covered with a mirage. Whereas a mirage is said to be very thin if the mirage appears only at the end of the white box, the part indicated by the letter A in Figure 1. Part A is the furthest part from the observer. In full, symbols A, B, C, D and E are used to indicate the appearance and visibility of a mirage, where A indicates that there is no visible mirage, B states there is a mirage but very low visibility (very thin), C is a mirage with low visibility (thin thickness), D there is a mirage with high visibility (thick), and E indicates there is a mirage with very high visibility (very thick). This observation location is always fixed during the observation. The position of the observer is determined by considering the trajectory of the sun, from sunrise to sunset, and the clarity of the visibility of the mirage. Airport runway ambient temperature and humidity data were obtained from Meteorology, Climatology and Geophysics Station of Blang Bintang, Aceh Besar, Aceh, Indonesia.

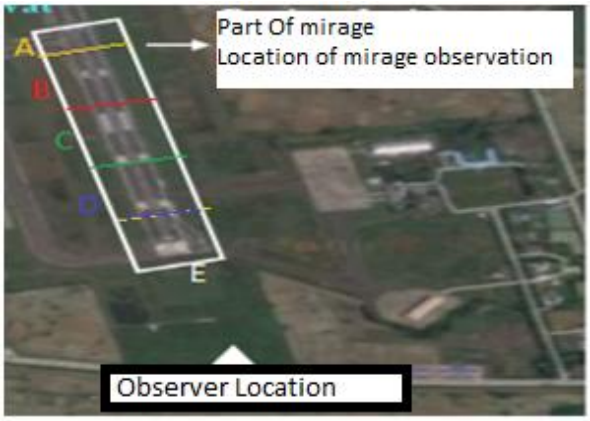

Fig. 1: Determining the reference point for observing mirages on SIM airport runway

3. Results and Discussions

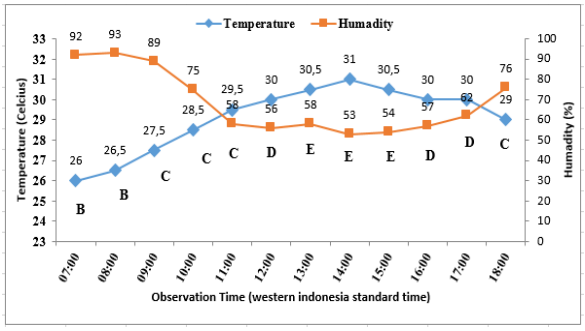

Fig. 2: Effect of temperature and humidity on visibility of mirage on August 28, 2017 [A: None, B: observed, very thin, C: observed, thin, D: observed, thick, E: observed, very thick]

Observations in the period from May to September 2017 showed that the temperature and humidity of the air obtained differed each day. In general, daytime temperatures are always higher than morning and evening temperatures. The measurement of air temperature at Blang Bintang Meteorology, Climatology and Geophysics Station is carried out with a mercury thermometer and other temperature sensors. The temperature sensor is installed at a height of 3 meters from the ground surface with a measurement range of 3 km. Mercury thermometers are installed at an altitude of 1.5 km

from ground level. Air temperature obtained with a mercury thermometer becomes a reference for measuring sensors that are on the runway. The temperature measured using the sensor is used to study the effect of temperature on the visibility of the mirage used by temperature.

In general, it has been observed that the measured air temperature on an airport runway tends to be higher than the air temperature on ordinary asphalt roads. This is because the airport runway environment is not obstructed by the surrounding trees. This condition also caused mirages to appear faster on airport runways compared to other places. Even so, mirages only occur when the runway surface gets thermal energy from sunlight radiation. If it rains, the mirage will not appear or will disappear from the runway surface because the air temperature decreases and the humidity increases. This shows that the phenomenon of mirage is strongly influenced by the temperature and humidity of the air. The observations show that during high temperatures mirages can be seen almost evenly along an airport runway with a height of about 1 meter.

Figure 2 shows one of the observations of a mirage visibility carried out on August 28, 2017 starting at 7:00 AM-18: 00 PM simultaneously with temperature and humidity measurements. As mentioned above, visibility of mirage is indicated by the letters A, B, C, D and E in the picture. In Figure 2, it can be seen that in general, temperature of air continues to increase rapidly, from 26.0^{0}C in the morning to 31.0^{0}C, at 14.00 PM, then gradually decreases to 29.0^{0}C at 18.00 PM. The results of these air temperature measurements show that there is a very significant difference between the temperature in the morning and the temperature in the afternoon until the afternoon, the difference is around 5.0^{0}C between the temperature in the morning with the afternoon and reaches around 3.0^{0}C between the temperature in the morning by evening. Similar results were also observed on other days, 30-31 August 2017 and 1 September 2017. The results of these air temperature measurements show that there is a significant difference between air temperature in the morning and air temperature in the afternoon to evening. The difference in air temperature in the morning with the evening time is very real can be seen on August 28, 2017, August 30 2017 and September 1, 2017.

Likewise, air humidity, as we can see in Figure 2, changes from morning to evening. In the morning, at 07.00 AM the air humidity reached 92 %, then along with the increase in temperature the humidity decreased to 53 % on 14.00 PM when the air temperature was at the highest, 31.0^{0}C. Humidity increased again slowly as the temperature dropped, and reached 76 % at the afternoon on 18.00 PM when the air temperature had dropped to 29.0^{0}C. This shows that from morning until late afternoon, air humidity tends to decrease regularly, while from noon to evening air humidity increases regularly. This also shows a significant difference between the morning humidity (92.00%) and the afternoon humidity (53.00%), namely around 39.00%. Likewise, the difference in humidity between the morning and the afternoon (76.00%), is around 16.00%. The difference in air humidity in the morning in real time can be seen on August 28, 2017 (Figure 2), August 30, 2017 (Figure 3) and September 1, 2017 (Figure 5).

Figure 3 shows the direct relationship between temperature and humidity of air of the airport environment. Likewise, the observation for other days, as shown in Figure 4 for August 31, 2017, and Figure 5 for September 1, 2017, was also relatively similar. The measurement results on these dates clearly show a very close relationship between changes in temperature of air with humidity, where in general it can be seen that high humidity occurs atlow temperatures or vice versa low humidity at high temperatures. It can also be observed that in general, the air temperature is low during the morning, while the humidity is generally high in the morning. In the morning the measured temperature values tend to be low due to several factors such as capacitance values, runway thermal diffusivity, level of asphalt surface flatness and environmental conditions. Furthermore, in general it can also be seen that air temperatures in the afternoon and evening are higher than those in the morning. The temperature reached its highest value just before noon and remained high until the afternoon. While air humidity is generally high in the morning even based on daily observational data shown in Figure 2, Figure 3, Figure 4 and Figure 5, the highest humidity value is obtained in the morning when the air temperature is the lowest. While the lowest humidity value is obtained during the day, when the temperature of air is highest.

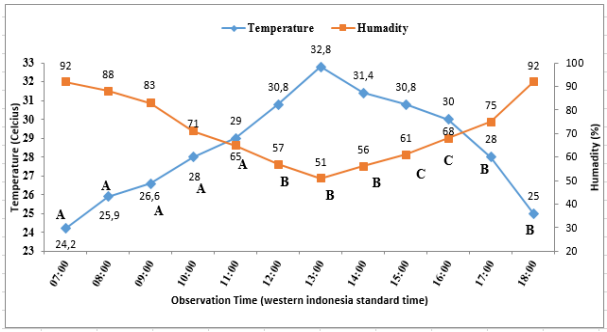

Fig. 3: Relationship between temperature and humidity of air and mirage appearance on August 30, 2017 [A: None, B: Yes, very thin, C: Yes, thin, D: Yes, thick, E: Yes, very thick]

As it can be seen in the figure, although in general changes in air humidity from morning to afternoon occur regularly, however at afternoon the humidity is very volatile. The simultaneous measurements of temperature and humidity show that from the morning until the late afternoon, changes in air temperature in line with changes in air humidity, where temperature of air rises regularly while humidity of air decreases regularly. While from afternoon to evening, although air temperature tends to remain, it turns out that the humidity changes very fluctuating. This implies that changes in air humidity from morning to afternoon can be attributed to changes in air temperature, but changes in air humidity from afternoon to evening that are very volatile cannot be attributed solely to changes in temperature, given the temperature of the air from afternoon to evening tends to be constant. Therefore, changes in humidity are actually also influenced by other variables, although based on measurement data from the morning until late afternoon, it can be said that changes in air humidity are mainly caused by changes in temperature. When the intensity of light reaching the surface of the earth decreases, the ambient air temperature of an object also decreases, because the surface temperature of the object, ie the surface of the earth, is also reduced. Thermal energy from objects will flow into the environment or vice versa

if the objects and the environment have different temperatures and the environment with objects connected thermally, in thermal contact, until the temperature of objects and the environment are the same, in equilibrium. When the surface temperature of the object is high, the water turns into water vapor. This causes the amount of water on the surface of the object to decrease. The same thing happens with water molecules in the air, when the temperature of the air rises, the water molecules in the air become steam.

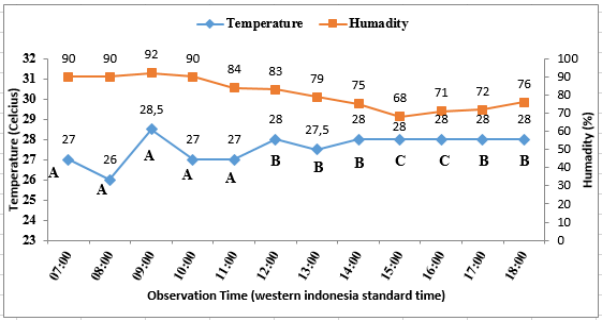

Fig. 4: Relationship between air temperature and humidity with visibility of mirage on August 31, 2017 [A: None, B: observed, very thin, C: observed, thin, D: observed, thick, E: observed, very thick]

In Figure 2, Figure 3, Figure 4 and Figure 5, the results of daily observations of the appearance of a mirage were performed from 7.00 AMuntil 18.00 PM. The observations found that on the certain day, August 28, 2018, Figure 2, it was seen that, although the visibility of mirage was still low indicated by the symbol B in the figure, a mirage had been seen since 7.00 AM in SIM airport runway. The more the mirage becomes clearer and thicker, the clearer and thicker the mirage can be seen, even reaching its peak of thickness starting from 13.00 PM until 15.00 PM. Then the thickness decreases gradually and the mirage still appears in the afternoon even though it is above 18.00 PM. The appearance of a mirage since the sun rises shows that air temperature is very influential in the appearance of a mirage. As it can be seen in Figure 2 and Figure 3 on August 28, 2017 and August 30, 2017 temperature has started to rise from the morning, and mirages have appeared since the morning.

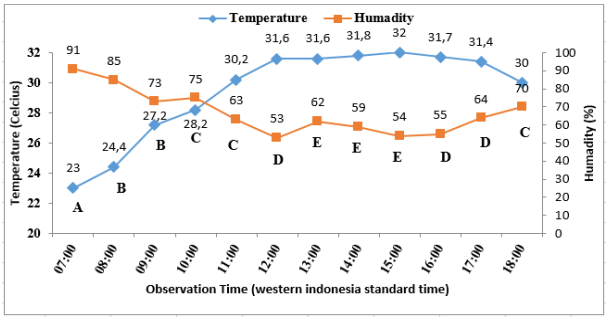

Fig. 5: Relationship between air temperature and humidity with visibility of mirage on September 1, 2017 [A: None, B: observed, very thin, C: observed, thin, D: observed, thick, E: observed, very thick]

In general, as it can be seen in Figure 2 and Figure 3, mirage appears when temperature is high, implying that it occurs when humidity is low, even in the morning. So that both in the morning and evening, mirage can be seen when high temperature and low humidity on the runway of SIM Airport. While the results of measurements made on August 31, 2017, Figures 4 and September 1, 2017, Figure 5 shows that no mirage can be seen on the second morning of the day. It turned out that temperature on the second morning of the day was very different from temperature on August 28, 2017 (26.0^{0}C), where on August 31, 2018, Figure 4, temperature on the morning reached 27.0^{0}C while on September 1, 2017, only reached 23.0^{0}C. While humidity on those two days, August 30 and September 1, 2017, was around 2 % lower than humidity on August 28, 2017 (92 %). Taking into account the data shown in Figure 2, Figure 3, Figure 4 and Figure 5, the thickest mirage is observed during the day when temperature is highest and humidity is the lowest. This shows the existence of a very crucial relationship between air temperature and humidity with the appearance of a mirage.

However, Figure 4 shows very interesting results and very different from observations on other days. Just at the morning, on 7:00 AM temperature has reached 27.0^{0}C, even though the surface of the earth has just received thermal energy from solar radiation. This temperature is higher than other mornings, where the average temperature in the morning is below 26.0^{0}C. Despite the high temperature on this morning, it turned out that a mirage had not yet appeared. This is probably caused by the level of humidity that is also very high so that the refraction that occurs in the air layer is very small and has not been able to bring up a significant temperature difference between each layer of air [21]. The measured humidity reaches 90 %. This humidity remained constant for almost half a day, starting from 7.00 AM until 10:00 AM and gradually decreased to around 83 % at 12.00 PM so that the mirage began to appear very thin at that hour. Only at 3:00 p.m. until 4:00 p.m. when humidity has fallen to 68 % the mirage can be seen more clearly even though it is still thin. The measurement results shown in Figure 4 clearly show the very important influence of air humidity on the appearance of a mirage. We observed that when air temperatures are high, mirage can easily appear even in the morning as long as air humidity decreases with temperature. But apparently, as observed in Figure 4, even though the air temperature is high in the morning, but if the humidity is high, and does not decrease with increasing temperature, the mirage does not appear. By observing the measurement results shown in Figure 2, Figure 3 and Figure 4, it can be seen that the most probable condition for a mirage to occur is when air temperature is high and humidity is low. If humidity is high and temperature is high, mirages don't appear.

Figure 5 shows that the observed temperature from 7:00 AM continued to increase until 13:00 PM and began to decrease slowly towards 18.00 PM at the afternoon. Conversely, air humidity decreases with increasing air temperature. Figure 5 shows mirage looks very thick (E) occurs during the daytime starting at 13.00 PM until 15.00 PM when air temperature reaches the highest temperature around 32.0^{0}C. At the same time air humidity dropped to the lowest value of 54%. The observations also showed a very clear change in the visibility of a mirage, from morning until late afternoon, that is, from a condition that had not yet appeared at 7.00 AM, indicated by the symbol A in the picture, then began to be seen at 8.00 AM until 9.00 AM although it is very thin, and then it becomes clearer and thicker from 13.00 PM until 15.00 PM. Mirage is still relatively thick at 16.00 PM until 17.00 PM and still appears until 18.00 PM even though it starts to thin again. In general it can be said that the

mirage looks thin in the morning and continues to increase in thickness before noon and decrease again towards the afternoon. This might be caused during the day from morning to evening, the weather is sunny, there are no thick clouds, clouds or rain that blocks the sun's radiation to reach the asphalt surface of the airport runway. The air temperature rises gradually from morning to afternoon and then decreases regularly in the afternoon. Likewise, air humidity, decreases regularly from morning to afternoon, and then decreases again from noon to evening. If during the day there are clouds or the weather is cloudy, the thermal energy received by the asphalt surface of the airport runway becomes uneven or reduced. This was observed in several cases such as those observed on August 30, 2017 and August 31, 2017, respectively as shown in Figure 3 and Figure 4. In Figure 4 it can be seen that temperature recorded in the morning tends to be the same as temperature at a day which is around $25{,}0^0$C. Likewise, humidity in the morning is the same as humidity in the afternoon. The same was also observed on August 31, 2017, temperature in the morning was relatively the same as in the afternoon, while humidity in the morning was higher than humidity in the afternoon, even if you notice humidity in the afternoon actually also being increased. On those two days, August 30, 2017 and August 31, 2017, the mirage did not appear in the morning, only appearing from 12.00 PM until 18.00 PM but with a very thin thickness (B).This is due to cloudy weather on both days. Measurement results on that day showed that despite high air temperatures and low humidity, mirages did not appear with high thickness (high visibility) were observed. This result implies that although temperature and humidity of the air are crucial for the appearance of a mirage, weather factors such as the presence of clouds and rain have a significant effect on the visibility of a mirage.

4. Conclusion

Mirage can clearly be observed on the runway ofSIM airport in Aceh. Temperature and humidity of surrounding air show a crucial role in the formation and visibility of mirage. In general, mirage occurs when temperature is high and humidity is low. The higher the temperature of the air and the lower the humidity of the air, the thicker mirage seen on the runway of SIM airport. Conversely, if air temperature decreases and humidity increases, mirage is weakened. The highest visibility of mirage can only be observed during the day, 12.00 PM - 15.00 PM, when temperature of air is highest andhumidity is the lowest. Despite high temperatures and low humidity, if there are clouds or rain, mirages cannot be observed. This implies that observations of a mirage isnot only provide information about temperature, humidity, pressure of air, but also provide information about the weather in the airport environment.

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