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INFILTRATION CAPACITY OF SANDY CLAY BY RAINFALL SIMULATOR TEST

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ABSTRACT

The study was a laboratory research aimed to identify the infiltration capacity value of one kind of soil in relationship with rainfall intensity and degree of surface slope. The rainfall intensity variations used were 45 mm/hr, 60 mm/hr and 75 mm/hr with the degrees of surface slope 5°, 15° and 30°.The result of the study indicates that the initial infiltration capacity value (f_o) was determined by rainfall intensity rather than the degree of surface slope. The maximum infiltration intensity (f_o) was proportional with the rainfall intensity but inversely proportional to the degree of surface acclivity. The degree of surface slope was > 30° and the maximum infiltration capacity value (f_c) is almost constant. In addition, the infiltration capacity rate curve decreased with the same value of rainfall intensity with the same degree of surface slope. The infiltration capacity rate decreased slower at the smaller surface slope than the bigger one. Based on the study result, the Horton formula has been modified.

Keywords: infiltration, sandy clay, rainfall intensity, slope surface degree, Horton formula.

INTRODUCTION

Background

Water is the most potential and renewable natural sources of life on earth. Water consists of vapor on air, water surface at sea, lake, river, ground water and so on. The amount of water is constant but the problem is the distribution and circulation process of this water is uneven. The existence of water in these places is due to a distribution and circulation process happens continuously due to natural process called hydrological cycle.

One of the hydrological cycle processes is infiltration. Infiltration is a process of permeation of rain water to earth into layer of soil and surface of ground water. The infiltration is influenced by many factors, among others: type of soil, soil humidity, condition of soil surface, surface acclivity, intensity of rainfall, etc.

One of the constraints faced in predicting the amount of surface runoff is the absence of accurate information about the amount of infiltration. In order to understand it, profound studies about the amount of infiltration in a region are necessary. Due to many factors affecting the infiltration mentioned previously, the writer is interested in studying the effect of rainfall intensity and surface acclivity on the amount of infiltration.

Objectives of the Study

a. To study the value and infiltration capacity curve of a soil type in relation to rainfall intensity and degree of surface slope.
b. To understand the value of coefficient "K" of Horton formula based on infiltration capacity of soil in relation to rainfall intensity and degree of surface slope.

Scope of the Problem

a. Type of soil under study was sandy clay with low plasticity.
b. Dimension model of soil physic was 10 cm thick and surface area 1 m^2.
c. Soil condition during research was arranged at density level and constant water content.
d. Soil surface condition used was barren surface condition.
e. Variations of rainfall intensity used were 45 mm/hr, 60 mm/hr, and 75 mm/hr.
f. Acclivity level reviewed was 5°, 15°, and 30°.
g. Evaporation during experiment was ignored.

LITERATURE REVIEW

A. Intensity of Rain

Short-term rainfall was stated in intensity per hour called rainfall intensity or rain intensity (mm/hr). The average rain intensity in t hour (It), according to Sosrodarsono and Takeda (1980) was stated in the following formula:

$$I_t = R_t / t \quad (1)$$

Where: R_t = rainfall for t hour.

As for this study, rain intensity used was artificial rain intensity produced by rainfall simulator.

The formula used to compute the rain intensity of artificial rain was rain simulator by Kusumastuti (1984):

$$I = \frac{V}{A\,x\,t}\,x\,600 \quad (2)$$

where:

I = rain intensity (mm/hr) A = size of cup (cm^2)
V = water volume in cup (ml) t = time (minute)

B. Infiltration

According to Asdak (1995), infiltration consists of three processes: a) the process where rain water gets

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through soil surface pores; b) the rain water catch in the soil; and c) the process of water flow to other places (bottom, side, and top). In that way infiltration can be defined as a process of permeation of rain water into soil layer and into the surface of ground water.

The infiltration is changeable according to the intensity of rainfall up to a certain limit, the amount of infiltration will be compatible with maximum absorption power from the soil. The infiltration velocity is changeable according to the intensity of rainfall called infiltration flow. According to Asdak (1995), the infiltration flow is determined by: a) amount of water available, b) characteristic of soil surface, and c) soil capacity to unload water on the soil surface. The maximum infiltration flow occurs at a certain condition called infiltration capacity.

According to Wilson (1993), factors affecting infiltration are: soil type, soil density, soil humidity, soil type covering, rain intensity, acclivity, etc.

C. Infiltration Capacity Curve

Infiltration capacity curve is a graphic illustration of changeable infiltration capacity according to time during and after the rain falls. Infiltration capacity in general is very high at the beginning and during the rain falls and will decrease due to various factors such as detention of surface, soil humidity, compaction due to rain, and so on. After a certain period (one to three hours), the infiltration capacity tends to be constant. The illustration of the infiltration capacity curve can be seen in Figure-1.

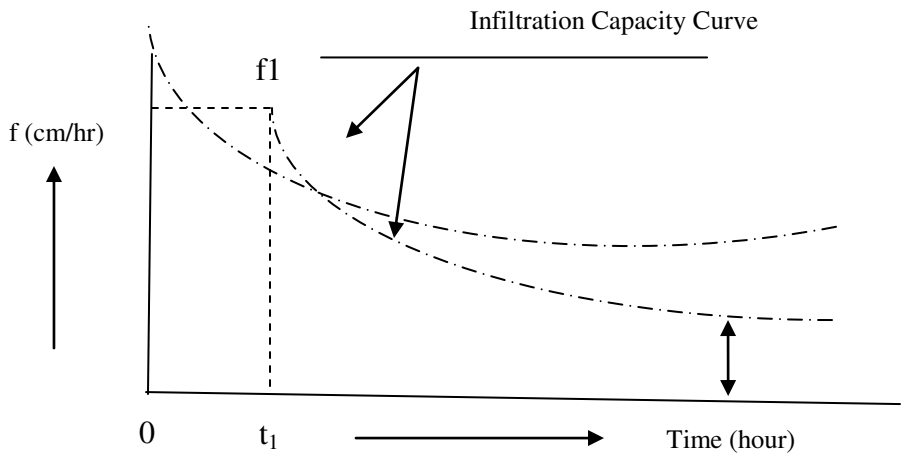

Figure-1. Infiltration capacity curve (Wilson, 1993).

where:

O = origin - time is calculated from the beginning of rain

T_1 = time when no infiltration and rain and nothing is left by interception catch/ dent soil.

a. Equation of infiltration capacity curve

Horton in Wilson (1993) formulates the infiltration capacity curve in a mathematical equation as follows:

$$f = f_c + (f_o - f_c)\, e^{-Kt} \quad (3)$$

where:

f = infiltration capacity at any moment t

K = a coefficient (constant figure)

f_o = initial infiltration capacity

t = time beginning from the first rain falls

f_c = infiltration capacity value after being constant

The completion of the equation is as follows:

$$t = \frac{-1}{K \log e} \log(f - fc) + \frac{1}{K \log e} \log(fo - fc) \quad (4)$$

This equation is equation of straight line: Y = m X + C with slope:

$$M = (-1) / K \log e \quad (5)$$

This straight line graphic is shown in Figure-2 as follows:

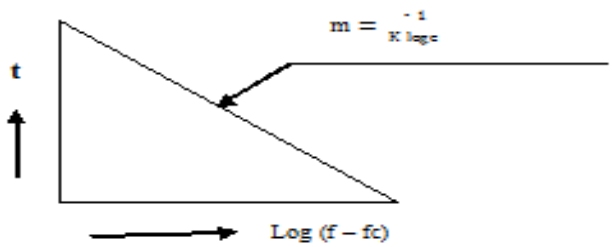

Figure-2. Equation curve Y = mX + C.

If the value of f is known at several times and f_c is also known, the straight line can be illustrated through equation of linear regression line Y = mX + C. According to Sudjana (1996), the values of coefficient m and C of the linear regression equation Y = mX + C are calculated as follows:

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$$m = \frac{n\sum(XiYi)-(\sum Xi)(\sum Yi)}{n\sum(X_i^2)-(\sum Xi)^2} \quad C = \frac{(\sum Yi)(\sum X_i^2)-(\sum Xi)(\sum XiYi)}{n\sum(X_i^2)-(\sum Xi)^2} \quad (6)$$

where:

X_i = log (f – f_c)
f = infiltration capacity at a certain time (mm/hr)
f_c = maximum infiltration capacity (mm/hr)
Y_i = t =observation time of infiltration capacity f (hr)

b. Measurement of infiltration capacity

Measurement of infiltration is meant to obtain illustration about infiltration flow and infiltration capacity as time function. There are two common methods used to determine infiltration capacity: An analysis of rainfall and runoff hydrograph and direct measurement method. Direct measurement method commonly used is Infiltrometer and Rainfall Simulator. And for this study Rainfall Simulator was used.

The basic principle of this tool is artificial rain maker with various intensities as needed. This artificial rain will water a piece of land with certain size equals to the size of this tool. According to Soemarto (1987), the illustration of the result of this rain simulator experiment can be seen in Figure 3 as follows:

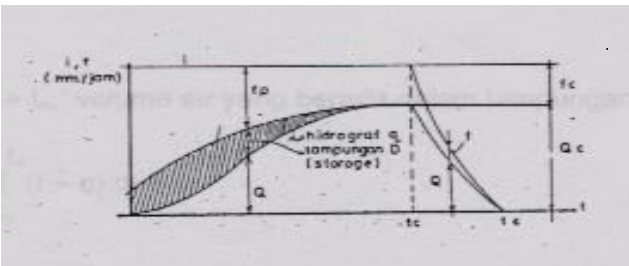

Figure-3. Relationship between rain, flowing, and infiltration (Soemarto, 1987).

Where:

I = rain intensity (mm/hr)
f_p = infiltration (mm/hr)
q = flowing (mm/hr)

At time t < t_c, I ≠ (f + q) to obtain f_p, D = f(q) must be calculated first.

At time t > t_c, water volume at the catcher is:

$$D = \int_{tc}^{te}(f+q)dt \quad (7)$$

It is assumed that : $\frac{f}{q} \approx \frac{fc}{qc}$ so that it is obtained:

$$D = (1 + {}^{fc}/_{qc}) \int_{tc}^{te} q dt \;\; or \;\; D = f(q) \quad (8)$$

From the explanation above, total rain intensity and run off can be computed:

$$P = \int_o^t I\, dt \;\; and \;\; Q = \int_o^t q dt \quad (9)$$

In which P and Q are measured in mm or ml. The size of infiltration volume can be computed from the following equation:

$$F = P - Q - D \text{ or } F + D = P - Q \quad (10)$$

Where:

F = cumulative of infiltration (ml),
P = cumulative of rain (ml),
Q = cumulative of flow (ml)
D = cumulative of catcher (ml)

METHODOLOGY

Research Method

The collection of data was done by direct measurement at the laboratory. The data measured were data on rain intensity and surface flow whereas acclivity surface was arranged based on problem statement. The values of infiltration capacity and coefficient "K" were obtained by analyzing the data using simple linear regression method.

Instrument and Material

a. Rainfall simulator
b. Five brass cylinder cups of diameter 7.3 cm and height 15 cm.
c. Tool for regulating the acclivity.
d. Wooden box of size 1.0m x 1.0 m and height 0.10 m as a place for soil. The base of this wooden box consists of timbers and wire mesh. In order to catch the surface flow, a truncated pyramid was put in one side made of flat zinc of which the end is in the form of pipe with diameter 2.5 cm as long as 10 cm.
e. Calibrated beakers with volume 50 ml, 100 ml, 250 ml, 500 ml, and 1000 ml, pail and used mineral water bottles and other tools.
f. Stopwatch.
g. Sandy clay
h. Compressor and mold base from standard compaction experiment.

RESEARCH IMPLEMENTATION

A. Research Location

The study was conducted at the Hydraulics / Hydrology and Soil Mechanics Laboratory of Civil Engineering, Faculty of Technology Hasanuddin University.

B. Research Procedure

- Preparation and soil examination

The soil used in this study was examined first at the Soil Mechanics Laboratory. Physical data and index needed are: gradation (percentage of smooth and rough fraction), Atterberg limits (liquid limit, plasticity limit and plasticity index), maximum weight of dry content and

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optimum water level and soil density in wooden box and its water level.

- Measurement of rain intensity.

The measurement of rain intensity was done nine (9) times according to rain intensity variations (three variations) and surface acclivity (three variations).

- Measurement of surface flow

Surface flow was caught on soil surface and flowed through truncated pyramid made of flat zinc installed at the bottom of soil box and caught in used mineral water bottles. Any change of time of surface volume flow was measured and recorded. When the flow of surface volume was constant, then the rain simulator was stopped and the time was recorded. The volume and time after the rain simulator was stopped was also recorded. The measurement of this surface flow was done nine (9) times.

RESULTS AND DISCUSSIONS

Soil Examination

Based on USC classification system of the results of gradation examination (rough fraction) and Atterberg (smooth fraction), soil classification obtained was CL that is sandy clay with low plasticity. Ground water level condition during the study was 14.997% and degree of density was 75.61%.

Initial Infiltration Capacity (f_o)

The value of initial infiltration capacity (f_o) as stated in Table-1, whereas the correlation between first infiltration capacity and rain intensity and acclivity level is shown in Figures 4 and 5. It is shown that the first infiltration capacity was in proportion with rain intensity and was not influenced by the degree of surface slope.

Table-1. Value of initial infiltration capacity, f_o.

Slope (degree)	Rain Intensity (mm/hour)		
	1	2	3
5	44.42	59.26	73.98
15	43.08	60.77	75.66
30	45.73	60.30	74.60

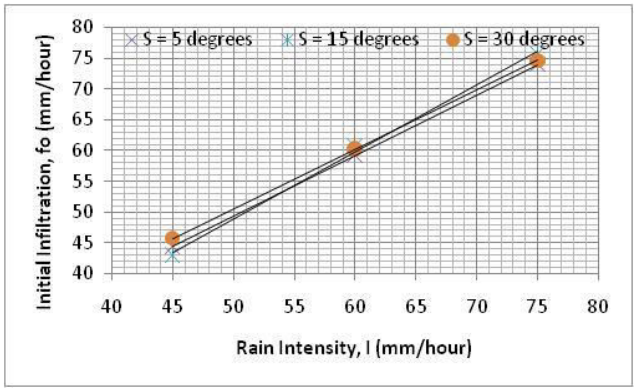

Figure-4. Relationship between (f_o) and (I).

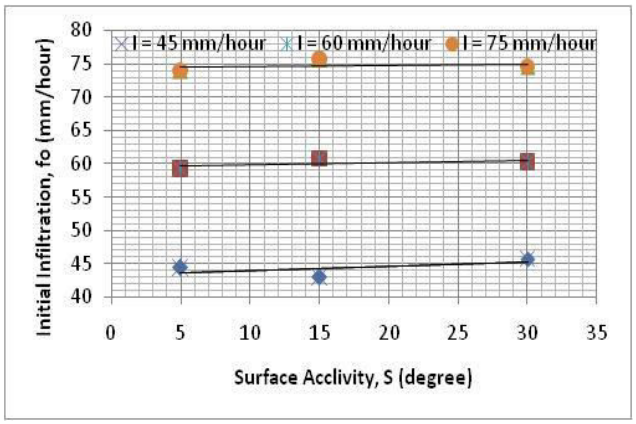

Figure-5. Relationship between (f_o) and (S).

Maximum Infiltration Capacity (f_e)

The value of maximum infiltration capacity (f_e) is shown in Table-2 and relationship of f_e with rain intensity and surface slope (acclivity) is shown in Figures 6 and 7.

It is shown that the maximum infiltration capacity was in proportion with rain intensity and in reverse proportion with surface slope degree. The decrease of f_c from slope 5^0 to 15^0 was bigger than 15^0 to 30^0 and tends to be constant at bigger slope. This illustrates that f_c was bigger at relatively small acclivity (< 15^0) compared with f_c at relatively big slope (> 15^0).

Table-2. Maximum infiltration capacity (f_c).

Slope (degree)	Rain Intensity (mm/hour)		
	45	60	75
5	25.91	36.28	46.25
15	21.12	33.49	42.42
30	19.98	31.13	41.27

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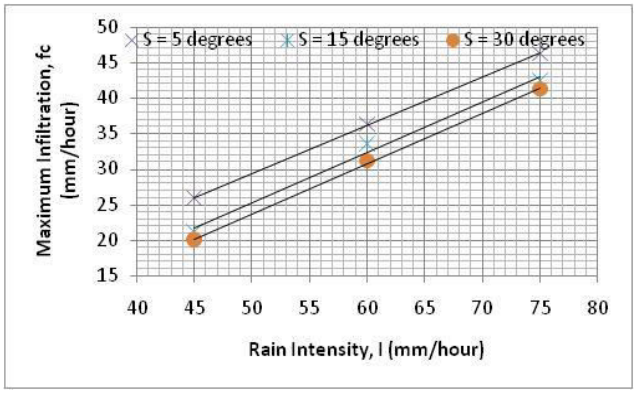

Figure-6. Relationship between (f_c) and (I) Infiltration Capacity Curve.

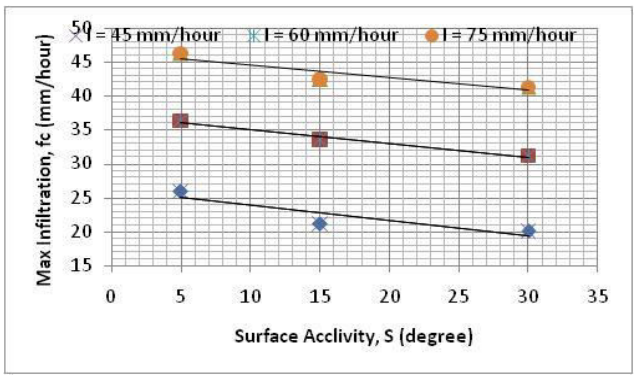

Figure-7. Relationship between (f_c) and (S).

The flow of infiltration capacity curve can be seen in Figures 8, 9, 10, 11, 12, and 13. In Figures 8, 9 and 10 it is shown that the flow of infiltration capacity curve at all rain intensity variations at each level of slope shows almost similar trend of decrease This provides information that the flow of infiltration capacity curve was in proportion with rain intensity at the constant slope level. The graphic also shows that at bigger rain intensity, the infiltration process was faster. This occurs due to the bigger rain intensity, the bigger the puddle of water on the soil surface, so that the water volume that will infiltrate will also be bigger. It is also seen at bigger rain intensity, the value of maximum infiltration capacity was achieved faster compared with the smaller rain intensity.

Figures 11, 12, and 13 show the trend decrease of infiltration capacity at a certain rain intensity was different from each acclivity level. At the slope level 5 degrees, the trend decrease of infiltration capacity was slower until it reached the maximum infiltration capacity value (constant) so that the curve was rather flat, but the value of maximum infiltration capacity (constant) was achieved faster. Whereas at the slope level 15 degrees, the trend decrease of infiltration capacity was rather faster compared with the acclivity 5 degrees, but the value of maximum infiltration capacity was slower to achieve. At the slope 30 degrees, the trend decrease of infiltration capacity was faster than the slope 5 degrees and 15 degrees, but the value of maximum infiltration capacity was slower to achieve. Therefore for the bigger slope, the trend decrease of infiltration capacity was faster, but the value of maximum infiltration capacity was achieved longer compared with the smaller slope. In that way the trend decrease of infiltration capacity was more determined by the surface slope level.

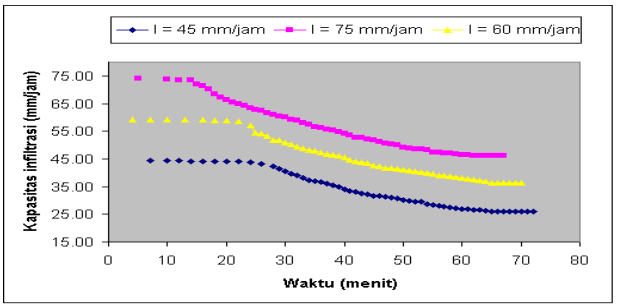

Figure-8. Infiltration capacity flow at S= 5^0.

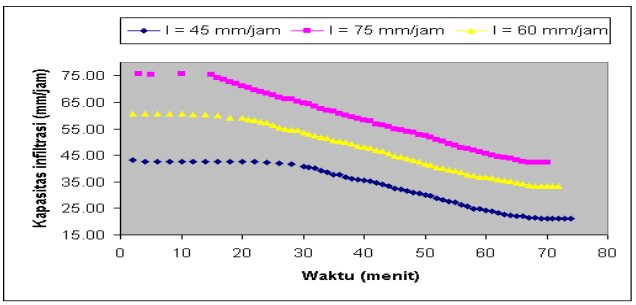

Figure-9. Infiltration capacity flow at S=15^0.

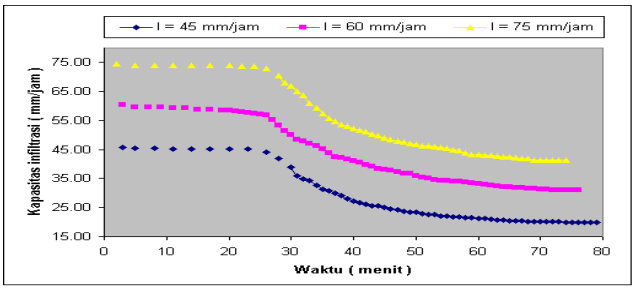

Figure-10. Infiltration capacity flow at S=30^0.

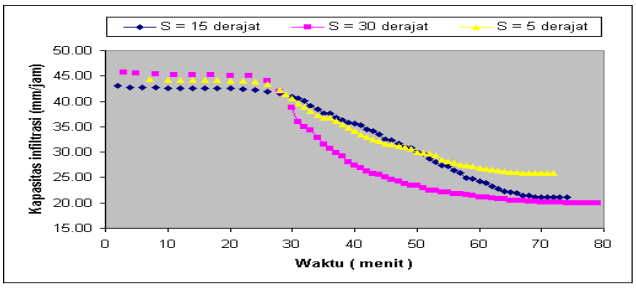

Figure-11. Infiltration capacity flow at I=45 mm.

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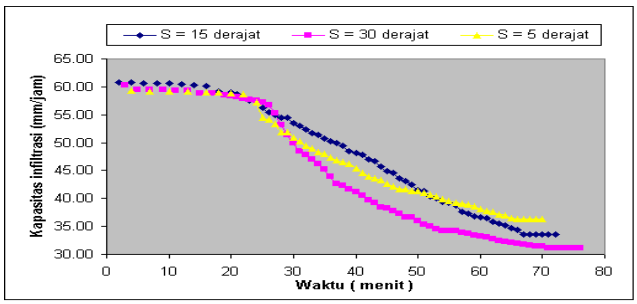

Figure-12. Infiltration capacity flow at I=60 mm/hr.

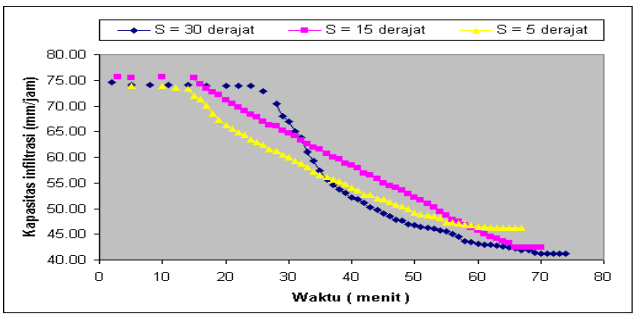

Figure-13. Infiltration capacity flow at I=75 mm/hr.

Value of Coefficient "K"

The computation result of the value of coefficient "K" can be seen in Table-3.

Table-3. Value of coefficient "K".

Slope (degree)	Rain Intensity (mm/hr)			Average
	45	60	75	
5	5.9138	5.8999	6.0033	5.9390
15	5.9344	5.7271	5.8624	5.8413
30	6.0458	5.9254	5.8335	5.9349
Average	5.9647	5.8508	5.8997	5.9051

Based on statistical test of the value of coefficient "K"; the average = 5.9051 minute^{-1} with standard deviation 0.0562 and coefficient of variation 0.9517%.

Modification of Horton Formula

The infiltration capacity curve by Horton in Wilson (1993) is stated in formula (3) : $f = f_c + (f_o - f_c)\, e^{-Kt}$. If $\lambda = (f_o - f_c) / f_o$, then the relationship between λ and acclivity (S) was made so that $\lambda = f(S)$ was obtained.. The value of $\lambda = (f_0 - f_c) / f_o$ in the slope level variation and rain intensity can be seen in Table-4 below:

Table-4. Value of $\lambda = (f_o - f_c)/f_o$.

Slope S (degree)	Rain Intensity (mm/hr)		
	45	60	75
5	0.4167	0.3878	0.3748
15	0.5097	0.4489	0.4393
30	0.5631	0.4837	0.4468

From the relationship between λ and S, some equation regressions of λ were obtained toward S and its determination coefficient. The strong relationship between λ and S was obtained at power type with determination coefficient $R^2 = 0.6412$ and equation regression $\lambda = 0.3197\, S^{0.132}$. The illustration of this equation regression can be seen in Figure-14 below:

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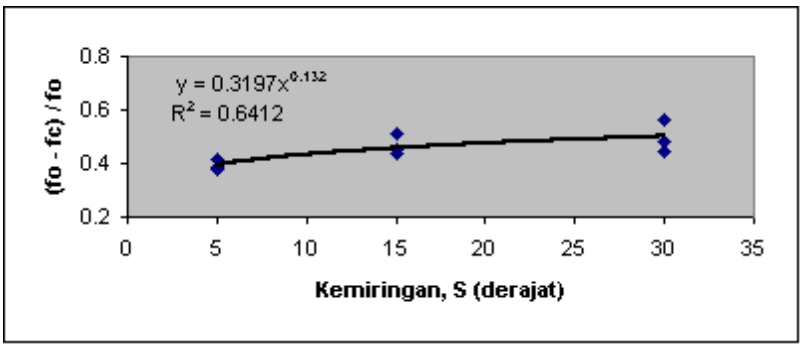

Figure-14. Relationship between ƛ = (f_o – f_c) f_o and acclivity (S).

For ƛ = (f_o – f_c) / f_o, then (f_o – f_c) = ƛ f_o, so that Horton equation:

$f = f_c + (f_o - f_c)\, e^{-Kt}$, can be modified into:
$f = f_c + ƛ\, f_o\, e^{-Kt}$

in which ƛ is the function of surface acclivity.

Based on this formula, it can be seen that the flow of infiltration capacity was influenced by several factors: maximum infiltration capacity (f_c), first infiltration capacity (f_o), surface acclivity (ƛ), coefficient K, and time (t)

CONCLUSIONS

a) Soil characteristic used in this study was sandy clay with percentage of smooth grain fraction = 52.29% and rough grain fraction = 47.71%, plasticity index = 23.00%, maximum dry content weight = 1.558 gr/cm3 and optimum water content = 17.80%. Early soil condition at the time of the research was water content = 14.997%, dry content weight during experiment = 1.178 gr/cm3 with intensity level = 75.61%.

b) Initial infiltration capacity (f_o) was determined more by rain intensity than the surface slope. Therefore, the greater the rain intensity, the greater the first infiltration capacity.

c) The maximum infiltration capacity (f_c) was in proportion with the rain intensity, but in reverse proportion with the surface slope. The greater the rain intensity, the greater the maximum infiltration capacity and vise versa: the greater the slope level, the smaller the maximum infiltration capacity at a certain rain intensity. At a certain slope (> 30 degrees) the maximum infiltration capacity tends to be constant.

d) The flow infiltration capacity curve tends to decrease which is almost similar for each rain intensity at a certain slope level. The trend decrease of the flow of infiltration capacity curve at smaller slope was slower than greater slope level. The greater the slope level, the faster the trend decrease of infiltration capacity. The value of maximum infiltration capacity at infiltration capacity curve is faster to achieve at the greater rain intensity condition and at the smaller slope level.

e) The value of coefficient "K" obtained from this study was around the value 5.9051 minute^{-1}, with standard deviation 0.0562 and coefficient variation 0.9517%.

f) Based on the results of this study, then the Horton formula:

$f = f_c = (f_o - f_c)\, e^{-Kt}$ can be modified to: $f = f_c + ƛ\, f_o\, e^{-Kt}$, in which ƛ is the function of surface acclivity with the relationship as:
$ƛ = 0.3197\, S^{0.132}$ (Slope , S in degree).

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