DOE/SC-ARM-TR-137

Laser Disdrometer Instrument Handbook

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Acronyms and Abbreviations

AMF	ARM Mobile Facility
ARM	Atmospheric Radiation Measurement
COMBLE	Cold-Air Outbreaks in the Marine Boundary Layer Experiment
DQPR	Data Quality Problem Report
DQR	Data Quality Report
ENA	Eastern North Atlantic
GCSS	Global Energy and Water Cycle Experiment Cloud System Study
GPCI	GCSS/WGNE Pacific Cross-Section Intercomparison
MAGIC	Marine ARM GPCI Investigations of Clouds
MOSAiC	Multidisciplinary Drifting Observatory for the Study of Arctic Climate
PC	personal computer
PM	preventive maintenance
QC	quality control
QME	Quality Measurement Experiment
SGP	Southern Great Plains
TWP	Tropical Western Pacific
VAP	value-added product
WGNE	Working Group on Numerical Experimentation

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1.0 General Overview

To improve the quantitative description of precipitation processes in climate models, the U.S. Department of Energy Atmospheric Radiation Measurement (ARM) user facility has been collecting observations of the drop size spectra of rain events since early in 2006. ARM purchased Parsivel2 laser disdrometers with America Recovery Act funds and they have proven robust in the field. They make observations of the particle size distribution over the range of 0.06 mm to 24 mm and classify precipitation type. To date they have been deployed on board the Horizon *Spirit* during the Marine ARM GPCI Investigations of Clouds (MAGIC) field campaign and one will be permanently deployed at ARM's Eastern North Atlantic (ENA) observatory. ARM initially deployed impact disdrometers at its Tropical Western Pacific (TWP) and Southern Great Plains (SGP) observatories (TWPC1,TWPC3, and SGPC1). Each of these three units was accompanied by a nearby tipping bucket rain gauge. In 2010, the tipping buckets were upgraded to weighing buckets. Subsequently, five video disdrometers were purchased. The purchase of a sixth video disdrometer is pending. The video disdrometers are permanently deployed at SGPC1, TWPC1, TWPC3, and in the near future at ENA. One video disdrometer is assigned to the second ARM Mobile Facility (ARM2). This handbook provides a detailed description of the Parsivel2 laser disdrometers and their datastreams.

2.0 Contacts

2.1 Mentor

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2.2 Instrument Developers

Parsivel2 Disdrometers
Ott Hydromet GmbH
Ludwigstrasse 16
87437 Kempten
Germany
www.ott.com

In USA sold by:

Hach Hydromet
P.O. Box 389
Loveland, Colorado 80539
www.hachhydromet.com

3.0 Deployment Locations and History

	Begin	End
MAGIC	9/24/2012	9/26/2013
ENA	2/2014	Ongoing

4.0 Near-Real-Time Data Plots

http://plot.dmf.arm.gov/plotbrowser/

5.0 Data Description and Examples

Datastreams

Xxxpars2Cn.00
Xxxpars2Cn.b1

5.1 Primary Variables and Expected Uncertainty

The variables for the disdrometer are listed in Tables 1 thru 4. The performance of the Parsivel2 disdrometer has not been studied. The performance of an earlier model of Parsivel disdrometer, however, was evaluated in a field study. In this study three different types of disdrometers observed the same rain events for six months (Tokai et al. 2013). If the second model's performance is like the first one, then in terms of median volume diameter the Parsivel showed an absolute % bias of 9.7 and 11.8 in comparison to the 2-dimensional video disdrometer and Josss-Waldvogel impact disdrometer, respectively. In terms of liquid water content, the absolute % bias values were 17.5 and 21.3 respectively.

The Parsivel2 assigns a precipitation classification whenever precipitation is observed. The precipitation categories are:

Drizzle
Drizzle with rain
Rain
Rain, drizzle with snow
Snow
Snow grains
Freezing rain
Hail.

5.1.1 Primary Variables

Table 1. Parsivel2 datastream.

Quantity	Variable	Measurement interval	Units	Comments
base time in epoch	base_time	1 min	seconds since YYYY-mm-dd XX:XX:XX X:XX	
time offset from base_time	time_offset	1 min	seconds since YYYY-mm-dd XX:XX:XX X:XX	
time offset form midnight	time	1 min	seconds since YYYY-mm-dd XX:XX:XX X:XX	
north latitude	lat	constant	degrees	permanent deployments have constant latitude; latitude from shipboard deployments is in separate navigation datastreams.
east longitude	lon	constant/ variable	degrees	Permanent deployments have constant longitude; longitude from shipboard deployments is in separate navigation datastreams.
altitude	alt	constant/ variable	meters above sea level	
number of drops/particless	number_detected_particles	1 min	counts	
weather code	weather_code	1 min	integer	SYNOP WaWa Table 4680
average diameter of particle class	particle_size	1 min	millimeters	
precipitation rate	precip_rate	1 min	millimeters/hour	
smallest particle	diameter_min	1 min	millimeters	
largest particle	diameter_max	1 min	millimeters	
moments of particle size distribution	moment1…moment 6	1 min	mm/m^3, mm^2/m^3, mm^3/m^3, mm^4/m^43 mm^5/m^3, mm^6/m^3	
number density	Number_density	1 min	$1/(m^3 \cdot m)$	
raw fall velocity	raw_fall_velocity	set of 32constants	m/s	

Quantity	Variable	Measurement interval	Units	Comments
fall velocity after Lhermite	fall_velocity_calculated	set of 32constants	m/s	Lhermite, 2002
raw particle size distribution	raw_spectrum		counts	matrix (32 x 32) of counts for particles observed in 32 possible particle classes at 32 possible fall velocities.
class size width	class_size_width		mm	
median volume diameter	median_volume_diameter	1 min	mm	
liquid water distribution mean	liquid_water_distribution_mean	1 min	millimeters	
liquid water content	liquid_water_content	1 min	mm^3/m^3	
radar reflectivity	equivalent_radar_reflectivity	1 min	dBZ	S band
radar reflectivity	equivalent_radar_reflectivity_ott	1 min	dBZ	S band reflectivity determined by Ott software.
distribution slope	lambda	1 min	1/mm	assumes Marshall-Palmer distribution
distribution intercept	intercept_parameter	1 min	1/(meters^3 · millimeters)	assumes Marshall-Palmer distribution
Mor visibility	mor_visibility	1 min	m	
laser band amplitude	laser_band_amplitude	1 min	counts	
sensor temperautre	sensor_temperature	1 min	degrees C	
heating current	heating_current	1 min	amps	
sensor voltage	sensor_voltage	1 min	volts DC	
snow depth intensity	snow_depth-intensity	1min	Mm/hr	

Note: lat/lon/alt refers to the ground where the instrument is sited, NOT the height of the sensor.

5.1.2 Expected Uncertainty

Table 2. Particle class specific for Parsivel2 disdrometer observations.

Diameter (mm)	Width (mm)	Ott fall velocity (m/s)	Lhermite velocity (m/s)
0.0629	0.1250	0.0500	0.2770
0.1870	0.1250	0.1500	0.8220
0.3120	0.1250	0.2500	1.3510
0.4370	0.1250	0.3500	1.8630
0.5620	0.1250	0.4500	2.3550
0.6870	0.1250	0.5500	2.8280
0.8120	0.1250	0.6500	3.2810
0.9370	0.1250	0.7500	3.7140
1.0620	0.1250	0.8500	4.1250
1.1870	0.1250	0.9500	4.5160
1.3750	0.2500	1.1000	5.064
1.6250	0.2500	1.3000	5.7210
1.8750	0.2500	1.5000	6.2990
2.1250	0.2500	1.7000	6.88010
2.3750	0.2500	1.9000	7.2330
2.7500	0.5000	2.2000	7.7620
3.2500	0.5000	2.6000	8.2820
3.7500	0.5000	3.0000	8.6330
4.2500	0.5000	3.4000	8.8610
4.7500	0.5000	3.8000	9.0050
5.5000	1.0000	4.4000	9.1200
6.5000	1.0000	5.2000	9.1780
7.5000	1.0000	6.0000	9.1950
8.5000	1.0000	6.8000	9.1990
9.5000	1.0000	7.6000	9.2000
11.000	2.0000	8.8000	9.2000
13.000	2.0000	10.400	9.2000
15.000	2.0000	12.000	9.2000
17.000	2.0000	13.600	9.2000
19.000	2.0000	15.200	9.2000
21.500	3.0000	17.600	9.2000
24.000	3.0000	20.800	9.2000

5.2 Definition of Uncertainty

N/A

5.3 Secondary/Underlying Variables

N/A

5.4 Diagnostic Variables

N/A

5.5 Data Quality Flags

If the data is missing for a sample time, a "missing_value" value of -999 is assigned to that field.

Table 3. Parsivel2 disdrometer data quality variables.

Quantity	Variable	Measurement interval	Min	Max	Delta
sample time	qc_time	1 min			
number of particles		1 min	0	none	N/A
precip rate		1 min	0	none	N/A
diameter max		1 min	0	24	
diameter min		1 min	0	24	

5.6 Dimension Variables

Table 4. Disdrometer dimension variables.

Quantity	Variable	Measurement interval	Unit
Base time in Epoch	base_time	1 min	seconds since YYYY-mm-dd XX:XX:XX X:XX
Time offset from base_time	time_offset	1 min	seconds since YYYY-mm-dd XX:XX:XX X:XX
Time offset form midnight	time	1 min	seconds since YYYY-mm-dd XX:XX:XX X:XX
north latitude	lat	once	degrees
east longitude	lon	once	degrees
altitude	alt	once	meters above sea level

Note: lat/lon/alt refers to the ground where the instrument is sited, NOT the height of the sensor.

6.0 Annotated Examples

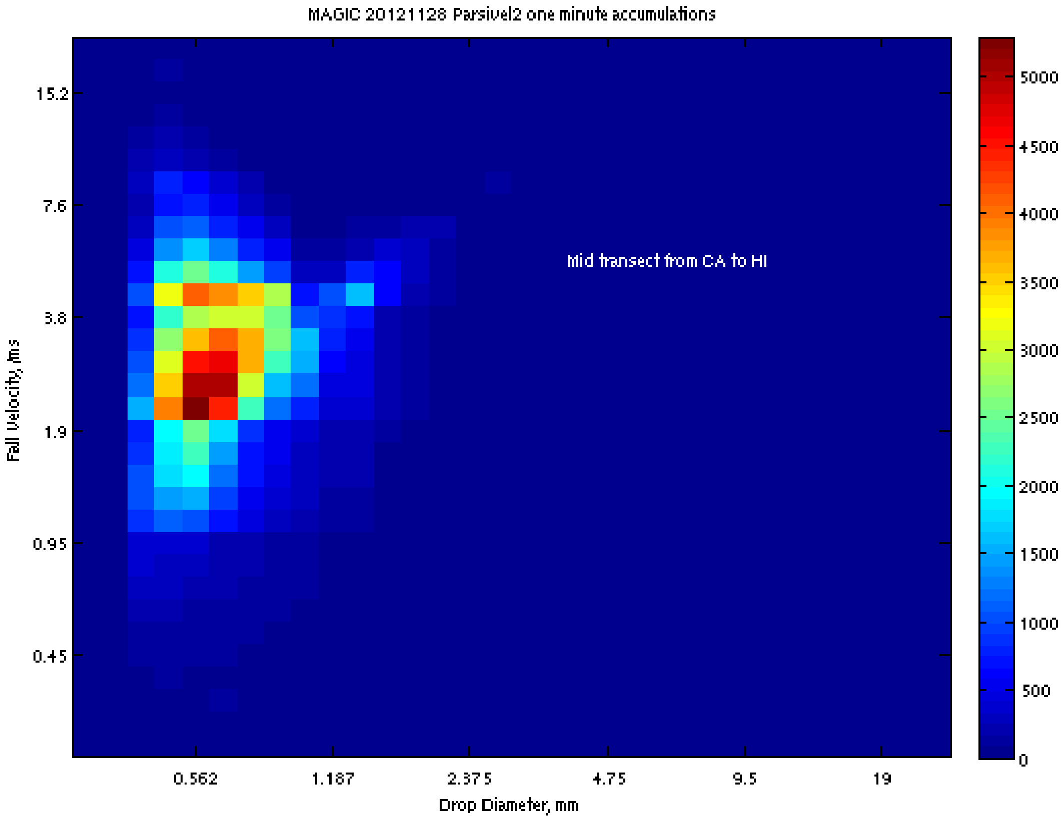

Figure 1. Two-dimensional histogram of the drop size distribution observed during the MAGIC field campaign. This figure shows the sum of all observations over a three-hour rain event with rain rates varying from 0 to 1 0mm/hr. Note that neither the x nor the y axis is linear in this plot.

7.0 User Notes and Known Problems

7.1 Outliers in the Data

It is common to find outliers in disdrometer data and they should be filtered out to obtain the best-quality data. Some hydrometeors will fall on the edge of the instrument's field of view. These will show up in the data as small drops moving too fast for their expected terminal fall speed. Other hydrometeors may enter the instrument's field of view after splashing on the device. These will show up as large drops with fall speeds less than expected for their terminal fall speed. Furthermore, insects, leaves, spider webs, etc. can lead to anomalous results. Most common outliers are screened by removing those with fall speeds greater than or less than 50% of Gunn and Kinzer (1949) empirically derived terminal fall speeds for rain drops. The raw data are provided in the b1 level files and researchers can choose what level of filtering they desire. Some may choose to use a maximum diameter threshold as well.

7.2 Difficulties Interpreting Parsivel2 (ld datastream) Observations During Periods of Frozen Precipitation

ARM purchased several Parsivel2s and a few Pluvio2 rain gauges with American Recovery Act funds to supplement ARM's observations of liquid precipitation. Both are permanently deployed at ENA and SGP; both are easy to deploy, reliable, and easy to maintain. They have also become baseline instruments for both AMF1 and AMF2 even if those facilities may be deployed in arctic locales.

Parsivel2s are optical disdrometers with a laser light source and a photodiode detector. The laser light is distributed across a sheet between the light source and detector. If no particles are present, the voltage signal from the photodiode is large. If particles fall through the instrument's field of view, the photodiode output is reduced; the larger the particle the smaller the output signal. The assumption is that only one particle is in the field of view at a time. The fall velocity of an observed particle is determined by the time the photodiode signal is reduced.

Rain drops typically have height-to-width ratios ranging from 1 (for small drops) to 0.7 (drops with diameters of 5 mm or larger). The observed diameters of rain drops are often assumed to represent their equivalent spherical diameters.

The axial ratios of particles of frozen precipitation can vary significantly. Depending upon the tilting angle and axial ratio of a particle as it falls through the Parsivel2 field of view, its reported width can be considerably different from its true width (Battaglia et al. 2010). For frozen particles with a 2 mm diameter, the ratio of reported to true width can vary from 0.6 to 1.6 depending upon tilting angle and axial ratio. For particles with 5 mm diameters, this ratio is reduced and varies from 0.8 to 1.15, again depending upon tilting angle and axial ratio. The ratio of observed fall velocity to actual fall velocity varies from 0.6 to 1.3 for 2 mm particles and from 0.4 to 2.0 for 5 mm particles.

Both particle size and fall speed are used to determine values reported in the ld datastream. The raw observations for both are provided in the raw_spectrum variable. These raw values are used to compute others in the final b1 version of the ld datastream. For example, precipitation intensity (R, mm/hr) is calculated from the equation below

$$R = \frac{pi}{6} * \frac{3.6}{10^3} * \frac{1}{F * t} * \sum n_i D_i^3$$

Where n_i = number of particles of particle size class i (20 size classes in total; 0.06 mm to 24.5 mm)

D_i= the diameter of particle class i

F = area of field of view

and t = accumulation time

Large values for D like those from observations of snowflakes result in large errors in R especially because D is raised to the third power in calculating R. This can be true for dendrites, needles, hail , etc. Hence, the results for R should not be trusted during snowfall. There are other variables in the ld datastream that are a function of diameter as well:

- Liquid water content
- Equivalent radar reflectivity factor
- Moments (1 thru 6) of the drop size spectrum
- Number density
- Liquid water distribution mean
- Median diameter
- Maximum diameter
- Minimum diameter
- Slope parameter
- Intercept parameter.

Snow_depth_intensity and weather_code are two scientific variables in the ld datastream that are least likely to have significant error due to large axial ratios of frozen particles. Snow_depth_intensity observations are a measure of the rate of snow accumulation and are determined by the manufacturer's proprietary method. No detailed description of this method is available. In 2019 the ARM Parsivel2s were upgraded to include the observation of this variable. This was done in anticipation of the Multidisciplinary Drifting Observatory for the Study of Arctic Climate (MOSAiC) and Cold-Air Outbreaks in the Marine Boundary Layer Experiment (COMBLE) campaigns with hopes of providing more meaningful data to arctic researchers. The weather code values follow the SYNOP WaWa standard and are also determined by the manufacturer's hardware. The impact of errors in precipitation rate, particle size, and sensor temperature on the observed weather_code values is unclear.

8.0 Frequently Asked Questions

N/A

9.0 Data Quality

9.1 Data Quality Health and Status

The following links go to current data quality health and status results:

- DQ HandS (Data Quality Health and Status)
- NCVweb for interactive data plotting using.

The tables and graphs shown contain the techniques used by ARM's data quality analysts, instrument mentors, and site scientists to monitor and diagnose data quality.

9.2 Data Reviews by Instrument Mentors

- **QC frequency:** Once or twice a week.
- **QC delay:** Three days behind the current day.
- **QC type:** DSview plots for instrument operation status, otherwise DQ HandS diagnostic plots.
- **Inputs:** None.
- **Outputs:** DQPR and DQR as needed.
- **Reference:** None.

9.3 Data Assessments by Site Scientist/Data Quality Office

All Data Quality Office and most site scientist techniques for checking have been incorporated within DQ HandS and can be viewed there.

9.4 Value-Added Procedures and Quality Measurement Experiments

Many of the scientific needs of the ARM facility are met through the analysis and processing of existing data products into “value-added” products or VAPs. Despite extensive instrumentation deployed at the ARM sites, there will always be quantities of interest that are either impractical or impossible to measure directly or routinely. Physical models using ARM instrument data as inputs are implemented as VAPs and can help fill some of the unmet measurement needs of the facility. Conversely, ARM produces some VAPs, not in order to fill unmet measurement needs, but to improve the quality of existing measurements. In addition, when more than one measurement is available, ARM also produces “best estimate” VAPs. A special class of VAP, called a Quality Measurement Experiment (QME), does not output geophysical parameters of scientific interest. Rather, a QME adds value to the input datastreams by providing for continuous assessment of the quality of the input data based on internal consistency checks, comparisons between independent similar measurements, or comparisons between measurement with modeled results, and so forth. For more information, see VAPs and QMEs web page.

10.0 Instrument Details

10.1 Detailed Description

The Ott Parsivel2 is a laser optical system housed in a metal “Y” shaped structure (Figure 2). A structure at the end of one branch of the “Y” houses the laser. The structure atop the other branch of the “Y” holds the detector. The field of view is midway between the transmitter and detector. The base of the “Y” is recessed to accommodate a vertical mounting pole for instrument deployment. Typically the device is set up at a height of ~6 feet (2 meters). Because the device weighs ~14 lbs (6.4 kg), a stable base like a concrete pad must be used to support the instrument. The instrument’s physical dimensions are 670 mm x 600 mm x 114 mm.

The laser operates at a wavelength of 780 nm with output power of 0.5 mW spread out over a beam 30 mm wide. Class 1 (21 CFR 1040.10 and 1040.11) also 1 (IEC/EN 60825-1 A2:2001).

10.2 List of Components

1. Parsivel2 device with 10-m cable.
2. RS485 to CAT5 converter (Nport MOXA 5520).
3. Power supply.
4. Enclosure for power supply and converter (power supply and converter located indoors).
5. Computer for instrument control and data acquisition.
6. Software for instrument control and monitoring, manufacturer's ADSO software.

Figure 2. Parsivel2 device. The transmitter is located in one housing and the detector in the other.

11.0 System Configuration and Measurement Methods

11.1 The Data Acquisition Cycle

During normal operation the disdrometer samples for one minute.

11.2 Firmware Overview

N/A

11.3 Processing Received Signals

The disdrometer's manufacturer provided software for data acquisition, analysis, and inspection. For the Parsivel2, the program is called ADSO and runs on a personal computer using Microsoft Windows7. ARM has always a virtual version of ARM's core PC for this instrument.

11.4 Siting Requirements

The disdrometer needs a level, firm base and an environment free from local wind distortions. Ideally it should be orientated perpendicular to prevailing winds.

11.5 Specifications

N/A

11.6 Theory of Operation

The Ott Parsivel2 is a laser optical system that produces a horizontal strip of light. Particles that pass through the light block a portion of the beam corresponding to their diameter. To determine particle speed, the duration of the diminished signal is measured.

11.7 Calibration

None required.

11.7.1 Theory

N/A

11.7.2 Procedures

N/A

12.0 History

N/A

13.0 User Manual

N/A

14.0 Routine Operation and Maintenance

Frequency: weekly

14.1 Inspection of Site Grounds Near the Instrument

Visually check the site grounds around the instrument for hazards such as rodent burrows, buried conduit trench settling, and insect nests.

Checklist response:

No problems noted.
Problem − Enter any applicable comments for this preventive maintenance (PM) activity.

14.2 Visual Inspection of Instrument Components

Conduit, cables, and connectors:

Check that all the conduits on the bottom of the control boxes are secure. Check all conduits from the control boxes to the sensors for damage. Check all sensor wires inside the control box for tightness and damage. Check all the connections at the sensors for damage, water intrusion, and tightness.

Checklist response:

No problems noted.
Problem − Enter any applicable comments for this PM activity.

14.3 Check Screen for Error Messages and Current Weather Conditions

Checklist response:

No problems noted.
Problem − Enter any applicable comments for this PM activity.

14.4 Active Maintenance and Testing Procedures

14.4.1 Disdrometer Maintenance

Keep sensor free of leaves and/or other debris.

14.4.2 Disdrometer Testing

Precipitation events should show particles accumulating in particle-versus-velocity plot.

Checklist response:

No problems noted.
Problem − Enter any applicable comments for this PM activity.

15.0 Software Documentation

Disdrometer: ingest software.

16.0 Citable References

Battaglia, A, E Rustemeier, A Tokay, U Blahak, and C Simmer. 2010. “Parsivel snow observations: A critical assessment.” *Journal of Atmospheric and Oceanic Technology* 27(2): 333−344, https://doi.org/10.1175/2009JTECHA1332.1

Gunn, R, and GD Kinzer. 1949. “The terminal velocity of fall for water droplets in stagnant air.” *Journal of Meteorology* 6(4): 243-248, https://doi.org/10.1175/1520-0469(1949)006<0243:TTVOFF>2.0.CO;2

Tokay, A, W Peterson, P Gatlin, and M Wingo. 2013. “Comparison of raindrop size distribution measurements by collocated disdrometers.” *Journal of Atmospheric and Oceanic Technology* 30(8): 1672−1690, https://doi.org/10.1175/JTECH-D-12-00163.1

17.0 Formulas Used in Data Processing

The following quantities are calculated for a distribution with a time interval t:

R Rainfall rate, [mm/h]
RA Rain amount, [mm]
W Liquid water content, [mm3 /m3]
Z Radar reflectivity factor, [mm6 /m3]
ZdB Radar reflectivity factor, [dB]
Dmax Largest drop registered, [mm]
N0 [1/(m3.mm)]
Λ Slope, [1/mm]
N(Di) the number density of drops of the diameter corresponding to size class i per unit volume, [1/(m3.mm)]

Input Data:

ni number of drops measured in drop size class i during time interval t
Di average diameter of the drops in class i mm
F size of the sensitive surface of the disdrometer m2
F = 0.0054 m2
t time interval for measurement s
t = 60 s (standard value)
v(Di) fall velocity of a drop with diameter Di m/s
ΔDi diameter interval of drop size class i mm, see drop size classes below

$$R = \frac{\pi}{6} \cdot \frac{3.6}{10^3} \cdot \frac{1}{F \cdot t} \cdot \sum_{i=1}^{20} (n_i \cdot D_i^3)$$

$$RA = R \cdot t/3600$$

$$RT = \sum_i RA$$

$$W = \frac{\pi}{6} \cdot \frac{1}{F \cdot t} \cdot \sum_{i=1}^{20} (\frac{n_i}{v(D_i)} \cdot D_i^3)$$

$$Wg = W/1000$$

$$Z = \frac{1}{F \cdot t} \cdot \sum_{i=1}^{20} (\frac{n_i}{v(D_i)} \cdot D_i^6)$$

$$ZdB = 10 \cdot \log Z$$

$$EK = \frac{\pi}{12} \cdot \frac{1}{F} \cdot \frac{1}{10^6} \cdot \sum_{i=1}^{20} \left(n_i \cdot D_i{}^3 \cdot v(D_i)^2\right)$$

$$EF = EK \cdot 3600/t$$

Dmax

$$N_0 = \frac{1}{\pi} \cdot \left(\frac{6!}{\pi}\right)^{\frac{4}{3}} \cdot \left(\frac{W}{Z}\right)^{\frac{4}{3}} \cdot W$$

$$\Lambda = \left(\frac{6!}{\pi} \cdot \frac{W}{Z}\right)^{\frac{1}{3}}$$

$$N(D_i) = \frac{n_i}{F \cdot t \cdot v(D_i) \cdot \Delta D_i}$$

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