บันทึกข้อความ

ส่วนราชการ ภาควิชาวิศวกรรมเครื่องกล คณะวิศวกรรมศาสตร์ **โทร.** 3309

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เรื่อง ขออนุมัติค่าตอบแทนการตีพิมพ์ผลงานในวารสารวิชาการ

เรียน รองคณบดีฝ่ายวิจัยและบริการวิชาการ ผ่านหัวหน้าภาควิชาวิศวกรรมเครื่องกล

อ้างถึง ประกาศมหาวิทยาลัยอุบลราชธานี เรื่อง หลักเกณฑ์การจ่ายค่าตอบแทนการตีพิมพ์ผลงานในวารสารวิชาการ คณะวิศวกรรมศาสตร์ พ.ศ.2555” ลงวันที่ 26 ตุลาคม 2555 ตามความทราบแล้วนั้น

เนื่องด้วยบทความทางวิชาการของ ผู้ช่วยศาสตราจารย์ ดร.อดุลย์ จรรยาเลิศอดุลย์ ได้รับการตีพิมพ์ผลงานในวารสาร จำนวน 2 เรื่อง คือ

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ดังนั้น ภาควิชาวิศวกรรมเครื่องกล จึงใคร่ขออนุมัติค่าตอบแทนการตีพิมพ์ผลงานในวารสารวิชาการในเรื่องดังกล่าวข้างต้น โดยมีรายละเอียดตามเอกสารที่แนบมาพร้อมนี้

จึงเรียนมาเพื่อโปรดพิจารณา

(ดร.อดุลย์ จรรยาเลิศอดุลย์)
ผู้ช่วยศาสตราจารย์ ภาควิชาวิศวกรรมเครื่องกล
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หัวหน้าภาควิชาวิศวกรรมเครื่องกล
12 พฤศจิกายน 2555

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2.5 สถานะในบทความวิจัยเป็น

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- ○ ผู้รับผิดชอบบทความ (corresponding author)
- ☑ ผู้มีส่วนร่วมในบทความ

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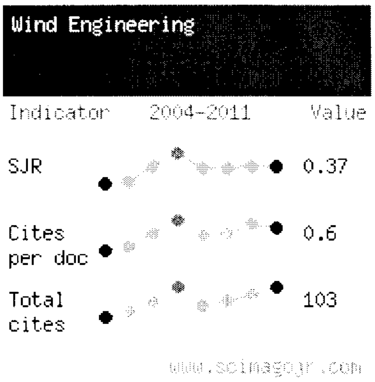

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Wind Energy Potential Assessment as Power Generation Source in Ubonratchathani Province, Thailand

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Wind Energy Potential Assessment as Power Generation Source in Ubonratchathani Province, Thailand

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ABSTRACT

In this paper, the hourly measured wind speed data for years 2008-2010 at 10 m, 30 m and 40 m height for Ubonratchathani province in kingdom of Thailand have been statically analyzed to determine the potential of wind power generation. Weibull distribution parameters have been estimated and compared annually and on monthly bases using two methods; the graphical method and the another method, designated in this paper as approximated method, which depends on the standard deviation and average wind speed. The average annual wind power density was found to be 19.13 W/m^2 for 10 m height, 83.14 W/m^2 for 30 m height and 91.45 W/m^2 for 40 m height. Weibull probability function, using Weibull parameters estimated from the approximated method, has shown to provide more accurate prediction of average wind speed and average power density than the graphical method. In addition, the monthly and annual variations of capacity factors have been studied to ensure optimum selection of wind turbine generators.

Keywords: wind energy potential, wind power generation, turbine, Weibull and Rayleigh distribution functions

1. INTRODUCTION

The growing environmental concern of air quality around the world has created a move to green sources of energy such as wind and solar which provide a pollution-free electricity. Wind is plentiful source available in the nature which could be utilized by mechanically converting wind power to electrical energy using wind turbine. In the last decade, the wind power potential has been studied in many countries worldwide [1-6].

Thailand is located in the south-east of Asia. Fig. 1 shows ASEAN power grid interconnection projects (APG) which establish by ASEAN Plan of Action Energy Cooperation (APAEC) in 2003 to maximize the use of regional power and resources. Table. 1 shows electricity consumption for the whole country from 1990 to 2009 [7], which increasing 352.83% in last two decades. As is known, the petroleum crisis in the end quarter of the 20th century has turned the attention of universities and other investigation foundations to new and renewable energy resources. Wind is rapidly becoming a practical source of energy for electric utilities around the world. Many firms in different countries have undertaken

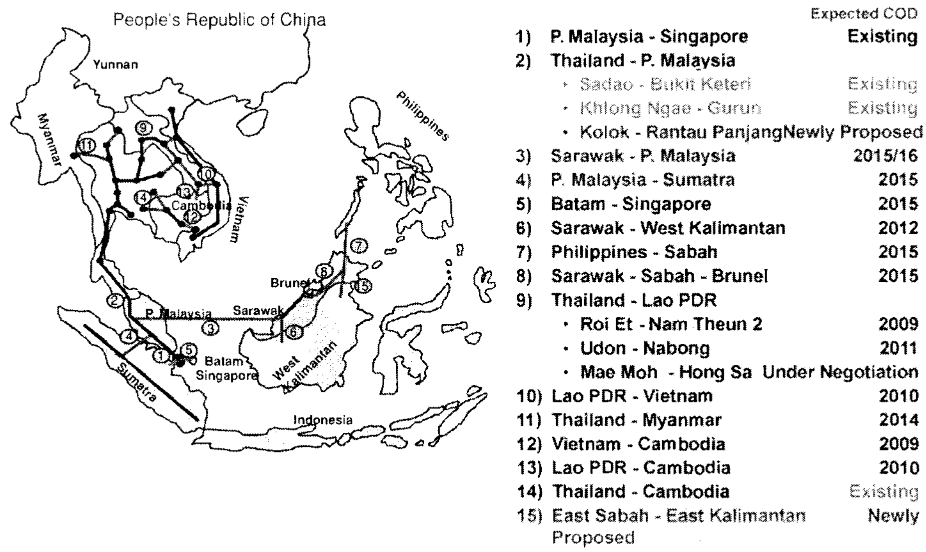

Figure 1: ASEAN power grid interconnection projects.

Table 1: Electricity consumption and percent of electricity import for the whole country from 1988–2009

Year	Electricity consumption for whole country (GWH)	Import of electricity (GWH)	Percent of electricity import (%)
1990	38,202.96	599.50	1.57
1991	44,238.87	593.11	1.34
1992	49,331.17	479.88	0.97
1993	55,231.29	644.51	1.17
1994	62,558.02	870.82	1.39
1995	70,870.31	699.12	0.99
1996	77,082.95	805.61	1.05
1997	81,998.02	745.63	0.91
1998	79,899.63	1,622.71	2.03
1999	80,985.50	2,255.66	2.79
2000	87,747.09	2,966.26	3.38
2001	93,020.68	2,881.76	3.10
2002	99,407.11	2,812.18	2.83
2003	106,207.83	2,473.41	2.33
2004	114,325.66	3,377.85	2.95
2005	120,637.37	4,371.89	3.62
2006	127,237.24	5,151.85	4.05
2007	132,492.12	4,488.36	3.39
2008	134,936.63	2,783.57	2.06
2009	134,792.89	2,460.09	1.83

development of commercial wind power plants. Wind is expected to be an important source of electric energy in the future in many regions of Thailand.

In order to study wind power in a particular site, the long-term records of wind speed have to be statistically analyzed. Apractical method of quantitative analysis of wind data can be performed by establishing the wind speed pattern, level and prevailing direction. To avoid the time and expense associated with processing multiple year data records of hourly wind speed data, it is very important to describe the variation of wind speeds with statistical functions for optimizing the designof the systems. The most widely used functions, which are used to fit a measured wind speed probability distribution in a given site over a certain period of time, are Weibull and Rayleigh distribution functions. Weibull distribution has been used to assess the potential of wind power in many countries [8-12]. The Rayleigh distribution has been also widely used to fit the measured probability distribution functions for different locations [13-17].

This paper presents a comprehensive analyze of the wind power density in Ubonratchathani at 10 m, 30 m and 40 m heights. The wind speed data and distribution are used to analyze wind power potential for 3 years from 1st January 2008 to 31st December 2010. The data has been analyzed using the hourly recorded data at standard height of 10 m, 30 m and 40 m heights.

2. DATA COLLECTION AND SITE DESCRIPTION

The wind data were collected at the Khong Chiam meteorological station (latitude 15°33′ N, latitude 105°30′ E), which is located in Ubonratchathani province. The data collected are from 1st January 2008 to 31st December 2010. The sampling period is 60 minute and the altitude of the measurement point was 10 m, 30 m and 40 m above the ground. Table 2 shows the frequency of the wind speeds for height of 40 m for years 2008-2010. Wind speeds are frequently measured in integers so that each wind speed is measured many times during a year observations. From Table 2, the actual probability density function, are calculated using the relationship $f_i = n_i/N$, where N is the total number of wind data obtained in a specific month and n_i is the frequency of a particular wind speed value.

3. WEIBULL DISTRIBUTION

The probability distribution, which is widely used to describe the long-term records of wind speeds, is Weibull distribution. The probability density function of a Weibull distribution is given by

$$f_w(V) = \frac{k}{c}\left(\frac{V}{c}\right)^{k-1} \exp\left(-\left(\frac{V}{c}\right)^k\right); \ (k > 0,\ V > 0,\ c > 1) \tag{1}$$

where, k is the shape factor, c is the scalar factor, and V is the wind speed. The cumulative distribution function is given by

$$F_w(V \le V_0) = 1 - e\left[-\left(\frac{V_0}{c}\right)^k\right] \tag{2}$$

where, F_w represents the probability for the speed V to be less than or equal to V_0. There are several methods used to determine the shape factor and scalar factor [18-20]. In this paper two approaches has been used; the graphical method [20] and the approximated method [19].

Table 2: The frequency of wind speeds for height of 40 m for year 2008–2010

Speed (m/s)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0
January	334	196	135	199	177	229	195	291	182	110	66	48	22	15	7	9	9	5	1	0	0	2
February	278	192	168	186	183	226	217	240	148	120	40	25	11	4	2	0	0	0	0	0	0	0
March	285	253	186	222	193	307	224	246	129	96	47	25	5	6	4	3	1	0	0	0	0	0
April	331	305	232	291	184	265	186	163	87	68	15	16	7	5	2	2	0	1	0	0	0	0
May	393	311	247	273	221	289	175	147	64	55	19	16	9	4	3	4	2	0	0	0	0	0
June	347	325	200	290	217	249	172	175	67	60	22	16	9	9	1	1	0	0	0	0	0	0
July	356	282	206	237	204	251	179	202	107	103	43	38	14	6	4	0	0	0	0	0	0	0
August	354	261	205	269	200	273	162	180	98	99	43	43	16	18	3	2	3	2	1	0	0	0
September	625	367	226	230	153	198	155	84	53	46	10	8	4	1	0	0	0	0	0	0	0	0
October	490	270	174	191	130	169	171	195	143	118	64	49	27	23	8	4	0	2	0	3	1	1
November	863	290	120	122	111	119	104	107	80	90	62	42	22	10	8	6	2	2	0	0	0	0
December	523	240	133	166	135	177	138	197	142	132	68	71	27	31	11	23	9	5	2	0	2	0

3.1. Graphical method

Equation (2) can be rewritten as [16]:

$$\ln\left[-\ln\left(1-F(V\le V_0)\right)\right]=-k\ln(c)+k\ln(V_0) \quad (3)$$

The values of the shape factor k and the scalar factor c can be determined by using least square fitting of the data, i.e.

$$y=b+mx \quad (4)$$

where,

$$y=\ln\left[-\ln\left(1-F(V\le V_0)\right)\right] \quad (5)$$

$$x=\ln(V_0)$$

Therefore, from (3)-(5), k and c can be calculated as follows

$$k=m \quad (6)$$

$$c=e^{\left(-\frac{b}{k}\right)} \quad (7)$$

3.2. Approximated method

The shaping factor and scale factor of Weibull distribution are given as [19]

$$k=\left(\frac{\sigma}{V_m}\right)^{-1.086} \quad (1\le k\le 10) \quad (8)$$

$$c=\frac{V_m}{\Gamma(1+1/k)} \quad (9)$$

where, σ is the standard deviation, V_m is the average wind speed, c is the gamma function which is defined by the following integral

$$\Gamma(x)=\int_0^{\infty} t^{x-1}e^{t-1}dt \quad (10)$$

4. WIND DATA PROCESSING

Wind data for Ubonratchathani for 3 years from 2008 to 2010 have been statistically analyzed. Table 3-5 shows, respectively, the wind data processing for Ubonratchathanifor years 2008-2010 for a height of 10 m, 30 m and 40 m. The average wind speed V_m for each month is calculated as follows

Table 3: Comparison between Weibull parameters calculated using graphical method and approximated method at 10 m height

Month	Average wind speed V_m (m/s)	Standard deviation σ (m/s)	Weibull approximated		Weibull graphical	
			Parameter k	Parameter c	Parameter k	Parameter c
January	2.25	1.51	1.541	6.881	1.291	2.645
February	2.11	1.34	1.637	5.525	1.387	2.679
March	2.07	1.33	1.622	5.545	1.372	2.694
April	1.97	1.24	1.653	5.041	1.433	2.463
May	**1.97**	**1.27**	**1.608**	**5.391**	**1.398**	**2.577**
June	2.04	1.30	1.627	5.423	1.327	2.374
July	2.11	1.44	1.519	6.717	1.179	2.392
August	2.10	1.41	1.536	6.482	1.316	2.343
September	2.09	1.47	1.470	7.324	1.610	2.210
October	2.02	1.37	1.529	6.307	1.359	2.513
November	2.18	1.42	1.589	6.146	1.459	2.923
December	**2.56**	**1.72**	**1.540**	**7.840**	**1.403**	**3.017**
Annual	2.12	1.40	1.57	6.22	1.38	2.57

Table 4: Comparison between Weibull parameters calculated using graphical method and approximated method at 30 m height

Month	Average wind speed V_m (m/s)	Standard deviation σ (m/s)	Weibull approximated		Weibull graphical	
			Parameter k	Parameter c	Parameter k	Parameter c
January	3.20	2.14	1.55	9.66	1.51	5.22
February	3.01	2.16	1.44	11.34	1.59	5.16
March	2.50	1.60	1.63	6.64	1.38	4.68
April	2.67	1.61	1.73	6.16	1.51	5.42
May	**2.62**	**1.60**	**1.70**	**6.25**	**1.49**	**5.62**
June	2.62	1.60	1.71	6.21	1.41	5.05
July	2.79	1.73	1.68	6.84	1.74	5.86
August	2.81	1.81	1.62	7.60	1.70	6.66
September	2.29	1.43	1.67	5.76	1.43	4.74
October	2.80	1.78	1.64	7.35	1.87	6.66
November	**3.82**	**2.58**	**1.53**	**11.88**	**1.60**	**6.46**
December	3.28	2.01	1.70	7.82	1.81	6.98
Annual	2.87	1.84	1.63	7.79	1.59	5.71

$$V_m = \frac{1}{N}\left[\sum_{i=1}^{N} V_i\right] \tag{11}$$

where, N is the number of records for each month. The standard deviation σ is also calculated for each month using

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(V_i - V_m)^2} \tag{12}$$

Table 5: Comparison between Weibull parameters calculated using graphical method and approximated method at 40 m height

Month	Average wind speed V_m (m/s)	Standard deviation σ (m/s)	Weibull approximated		Weibull graphical	
			Parameter k	Parameter c	Parameter k	Parameter c
January	3.91	2.16	1.90	7.45	1.65	6.34
February	3.72	2.02	1.94	6.85	1.69	5.82
March	3.64	1.99	1.92	6.83	1.67	5.80
April	3.31	2.11	1.63	8.74	1.41	5.73
May	**3.23**	**2.04**	**1.64**	**8.39**	**1.30**	**5.26**
June	3.29	2.12	1.61	8.95	1.41	5.80
July	3.50	2.14	1.71	8.34	1.37	6.09
August	3.53	2.11	1.75	7.94	1.53	6.75
September	2.83	1.81	1.62	7.58	1.38	5.59
October	3.46	2.33	1.53	10.70	1.36	5.60
November	**4.19**	**2.56**	**1.71**	**9.91**	**1.88**	**7.18**
December	3.73	2.27	1.71	8.81	1.42	6.04
Annual	3.53	2.14	1.72	8.37	1.51	6.00

Following the procedure presented in previous section and Weibull parameters (k and c) are determined using both approaches.

It can be seen from Tables 3-5 that the highest wind speed occurs in November while the lowest wind speed occurs in May at all heights studied. The smallest standard deviation σ is found to be in May. This indicates that the wind speed records are close to the average wind speed. The average annual wind speed is found to be 2.12 m/s for 10 m, 2.87 m/s for 30 m and 3.53 m/s for 40 m.

Fig. 2-4 shows the actual probability density function, Weibull probability distribution function using graphical method and approximated method for all height under consideration. These functions are used in the coming section to predicate the average wind speed and average wind power corresponding to each height.

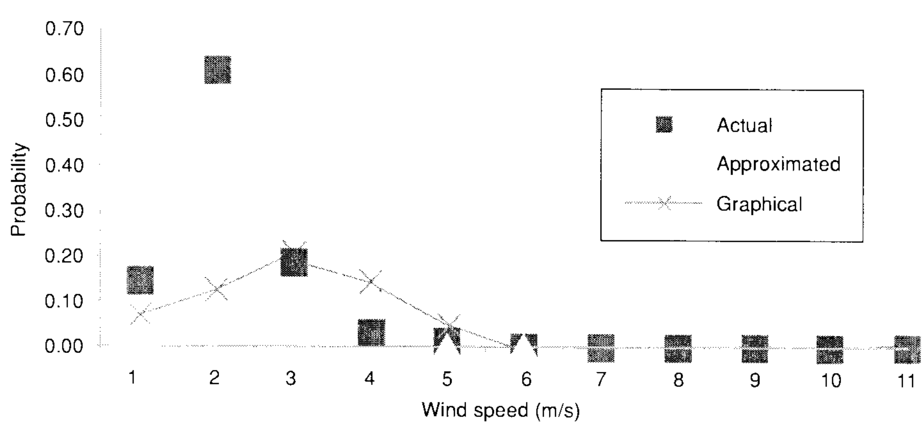

Figure 2: Probability density function of wind speeds at 10 m height.

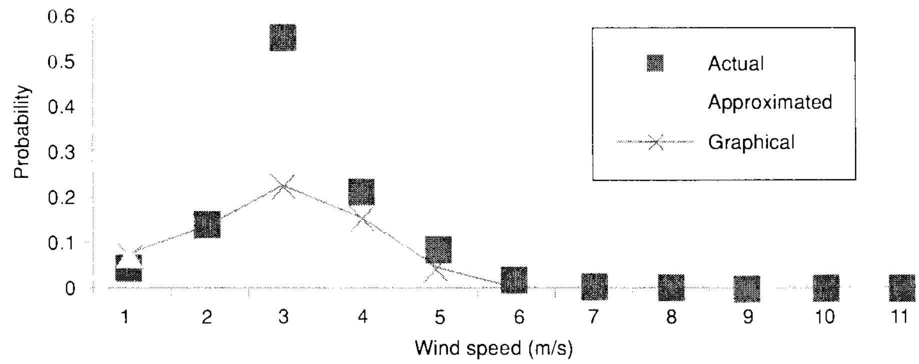

Figure 3: Probability density function of wind speeds at 30 m height.

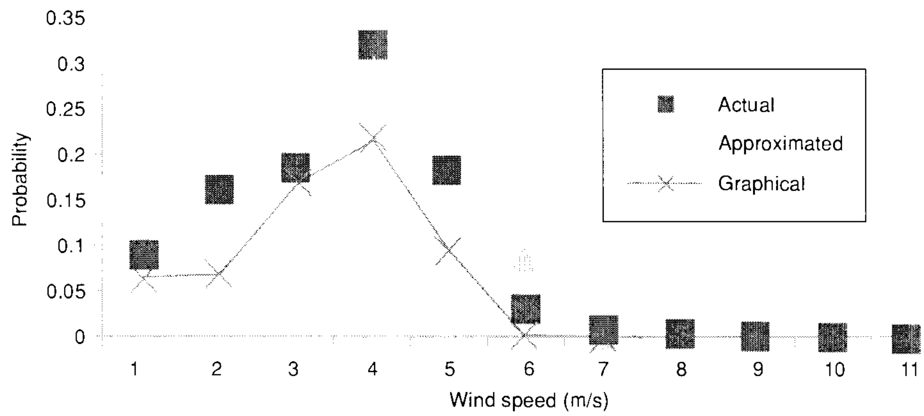

Figure 4: Probability density function of wind speeds at 40 m height.

5. ESTIMATION OF AVERAGE MONTHLY WIND SPEED AND POWER DENSITY

The monthly average wind speed using Weibull and Rayleigh distributions is determined, respectively, as [14]

$$V_{mWei} = c\Gamma\left(1+\frac{1}{k}\right) \tag{13}$$

The power of the wind per unit area is given as

$$P_w = \frac{1}{2}\rho V^3 \tag{14}$$

where, ρ is the air density and given as 1.225 kg/m^3.

The average power density for each month is calculated using actual probability density distribution for the specified month, which is calculated using Equation (1), and is given as

$$P_{Wma} = \sum_{i=1}^{n}\frac{1}{2}\rho V_{mi}^3 f(V_i) \tag{15}$$

where, The subscript m stands for the month and n is the number of records for the specified month.

The average power density using Weibull probability distribution is calculated as follows [14]

$$P_{WmW} = \frac{1}{2}\rho c^3 \Gamma\left[1 + \frac{3}{k}\right] \quad (16)$$

The average monthly wind speed and average monthly power density at 10 m, 30 m and 40 m heights estimated from actual probability density function, Weibull probability distribution function using graphical method and approximated method are presented in Table 6, Table 7 and Table 8, respectively. The last raw of each table shows the annual

Table 6: Monthly wind speed and power density calculated using Weibull parameters for years 2008–2010 in Ubonratchathani at a height of 10 m

		Meteorological		Weibull approximated		Weibull graphical	
Month	V_m	P/A (W/m²)	E/A (kWh/m²/month)	P/A (W/m²)	E/A (kWh/m²/month)	P/A (W/m²)	E/A (kWh/m²/month)
January	2.25	6.98	5.19	16.65	12.39	11.47	8.54
February	2.11	5.75	3.87	14.60	9.81	9.99	6.71
March	2.07	5.43	4.04	15.25	11.35	10.45	7.77
April	1.97	4.68	3.37	11.04	7.95	7.15	5.15
May	**1.97**	**4.68**	**3.48**	**13.68**	**10.18**	**8.72**	**6.49**
June	2.04	5.20	3.74	10.33	7.44	7.75	5.58
July	2.11	5.75	4.28	12.80	9.52	10.48	7.80
August	2.10	5.67	4.22	11.67	8.68	7.61	5.66
September	2.09	5.59	4.03	11.00	7.92	3.77	2.71
October	2.02	5.05	3.76	14.58	10.84	8.68	6.46
November	2.18	6.35	4.57	20.63	14.85	11.40	8.21
December	**2.56**	**10.28**	**7.65**	**24.58**	**18.29**	**13.85**	**10.31**
Annual	2.12	71.42	52.20	176.81	129.22	111.33	81.3

Table 7: Monthly wind speed and power density calculated using Weibull parameters for years 2008–2010 in Ubonratchathani at a height of 30 m

		Meteorological		Weibull approximated		Weibull graphical	
Month	V_m	P/A (W/m²)	E/A (kWh/m²/month)	P/A (W/m²)	E/A (kWh/m²/month)	P/A (W/m²)	E/A (kWh/m²/month)
January	3.20	20.07	14.93	80.61	59.97	59.93	44.59
February	3.01	16.70	11.22	89.65	60.24	49.91	33.54
March	2.50	9.57	7.12	60.69	45.16	54.03	40.20
April	2.67	11.66	8.39	95.13	68.50	66.16	47.63
May	**2.62**	**11.02**	**8.20**	**72.26**	**53.76**	**76.06**	**56.59**
June	2.62	11.02	7.93	70.07	50.45	64.04	46.11
July	2.79	13.30	9.90	98.43	73.23	55.70	41.44
August	2.81	13.59	10.11	99.76	74.23	89.07	66.26
September	2.29	7.36	5.30	60.61	43.64	51.65	37.19
October	2.80	13.45	10.00	85.48	63.59	65.69	48.87
November	**3.82**	**34.14**	**24.58**	**102.49**	**73.79**	**94.94**	**68.36**
December	3.28	21.61	16.08	94.02	69.95	83.00	61.75
Annual	2.87	183.48	133.77	1009.20	736.51	810.18	592.54

Table 8: Monthly wind speed and power density calculated using Weibull parameters for years 2008–2010 in Ubonratchathani at a height of 40 m

		Meteorological		Weibull approximated		Weibull graphical	
Month	V_m	P/A (W/m^2)	E/A (kWh/m^2/ month)	P/A (W/m^2)	E/A (kWh/m^2/ month)	P/A (W/m^2)	E/A (kWh/m^2/ month)
January	3.91	36.61	27.24	85.97	63.96	82.23	61.18
February	3.72	31.53	21.19	62.39	41.92	59.79	40.18
March	3.64	29.54	21.98	64.05	47.65	61.31	45.61
April	3.31	22.21	15.99	103.17	74.28	93.59	67.39
May	**3.23**	**20.64**	**15.36**	**78.47**	**58.38**	**88.11**	**65.55**
June	3.29	21.81	15.70	111.25	80.10	97.45	70.17
July	3.50	26.26	19.54	171.73	127.77	122.22	90.93
August	3.53	26.94	20.04	136.13	101.28	123.13	91.61
September	2.83	13.88	10.00	97.52	70.21	91.76	66.07
October	3.46	25.37	18.88	100.86	75.04	94.96	70.65
November	**4.19**	**45.06**	**32.44**	**113.08**	**81.42**	**80.58**	**58.01**
December	3.73	31.79	23.65	104.42	77.69	107.07	79.66
Annual	3.53	331.65	242.00	1229.03	899.71	1102.20	807.01

average wind speed and annual wind power density. The maximum power density throughout the year is found in November and the lowest power densities occur in May. The Weibull distributions, using both approaches predicts the maximum and the minimum power densities at the right month. However, the approximated approach provides more accurate results than the graphical approach. Thus, the Weibull distribution, calculated using approximated approach, is accurately presenting the wind speed variation in Ubonratchathani.

6. WIND DIRECTION

Determining wind speed according to wind direction is important to conduct wind energy researches and displays the impact of geographical features on the wind. The wind direction is illustrated in polar diagrams and is measured clockwise in degrees. The cycle (360°) which divided in 16 sectors and each of them covers an arc of 22.5°. The frequencies are plotted in polar diagrams with the wind blows. The duration of the stillness as a fraction of time is presented with a specific cycle of appropriate radius at the center of each polar diagram. In Figs. 5, the wind data and the polar diagrams of Ubonratchathani for the years 2008-2010 are presented.

A comparison of the polar diagrams for the years studied, shows that the direction of wind blow in Ubonratchathani is characterized by a significant stability. The most probable wind direction for the three years period is on 157.5° in the three-quarter, which on the south-east. On the other hand, for all the years the stillness percentage is in the range of 15-48%.

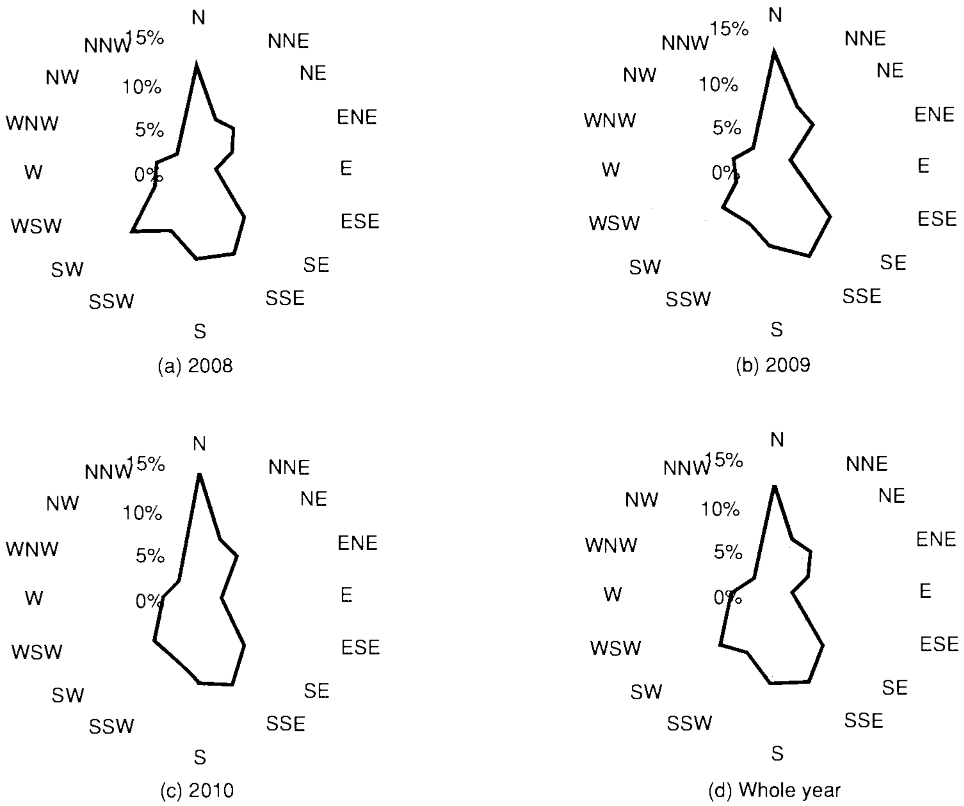

Figure 5: Polar diagram of wind direction for the year 2008-2010 inUbonratchathani (a) 2008; (b) 2009; (c) 2010; (d) whole year.

7. CONCLUSION

Detailed statistical study of wind speed and power at 10 m, 30 m and 40 m heights in Ubonratchathanifor the years 2008-2010 are presented. Wind speeds are modeled using Weibull probability function whose parameters are estimated from two different approaches; the graphical approach and the approximated approach. It is shown that the Weibull probability function, with parameters estimated from the approximated approach, predicts the wind speed and wind power more accurately than the other approach. Using Weibull parameters, estimated using the approximated approach, the monthly and annual capacity factors are calculated for selected commercial wind turbine generators at 10 m, 30 m and 40 m heights.

Finally, it worth mentioning that the current work is only a preliminary study in order to estimate the wind energy potential analysis of Ubonratchathani, in order to have a comprehensive wind data base and obtain good predictions prior to construction and installation of wind energy conversion systems. In assessing the wind power potential or choosing the suitable type of wind turbine, not only the wind data but also the site circumstances (terrain, different referred height, etc.) should be considered that this issue can be addressed for application of new wind energy generation technology.

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แบบเสนอขอรับค่าตอบแทนในการตีพิมพ์วารสารวิชาการ

1. **เอกสารประกอบการเสนอขอรับค่าตอบแทนในการตีพิมพ์วารสารวิชาการ**

1.1 แบบขอรับค่าตอบแทน

1.2 หนังสือขออนุมัติค่าตอบแทน เรียน รองคณบดีฝ่ายวิจัยและบริการวิชาการผ่านหัวหน้าภาควิชา

1.3 สำเนาบทความวิจัยที่ได้รับการตีพิมพ์ในวารสารวิชาการ

1.4 รายละเอียดวารสาร

1.5 เอกสารแสดงค่า Impact factor ของวารสารที่ตีพิมพ์

2. **รายละเอียดข้อมูลประกอบเสนอขอรับค่าตอบแทนในการตีพิมพ์วารสารวิชาการ**

2.1 ผู้เสนอขอรับค่าตอบแทน ชื่อ-สกุล [illegible]

2.2 ชื่อบทความวิจัย (ภาษาไทย) ....

(ภาษาอังกฤษ) A study of diffuser angle effect on ducted water current turbine performance using CFD

2.3 รายละเอียดของวารสาร

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2.5 สถานะในบทความวิจัยเป็น

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○ ผู้รับผิดชอบบทความ (corresponding author)

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Original Article

A study of diffuser angle effect on ducted water current turbine performance using CFD

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Abstract

The water current has used as the energy resource for long time however its velocity is very low therefore there are not found in wide range of uses. This study purposes accelerate water velocity by installing diffuser. The problems were analyzed by one dimension analysis and computational fluid dynamics (CFD); the domain covers the diffuser and turbine which substituted by porous jump condition is install inside. The flow was identified as axisymmetric steady flow, the inlet boundary is identified as uniform flow, all simulation use the same size of diffuser, only the diffuser angles are vary. The results show that velocities of water current in diffuser are increase when the diffuser angle are widen. The angle of diffuser is 20°, the velocity is increase to 1.96 times, compared to free stream velocity. If the angle was about 0-20° and 50-70° the force toward diffuser became high instantly; where as the force toward the rotor will be still and the maximum rate of diffuser augmentation possibly was 3.62 and rotor power coefficient was 2.14.

Keywords: water current turbine, diffuser, computational fluid dynamics, power augmentation, ducted water turbine

1. Introduction

The uses of kinetic energy of water current for generating electricity or pumping has been studied for long times, which mainly aims to use in remote areas (Fraenkel, 2006; Ponta and Jacovki, 2008; Ponta and Dutt, 2000; Myyers and Bahaj, 2006; Bahaj and Myers 2003; Khan *et al.*, 2008; Kiho *et al.*,1999; G MacPherson-Grant, 2005). According to the kinetic energy use from water current, a wind turbine-based knowledge at commercial level can appropriately be applied to that its capacity of energy distribution is as Betz limit. The wind turbine has its maximum power coefficient, $C_P = 0.59$, defined as energy produced by wind turbine per total energy available of wind. Although its capacity was 45% developed, it still challenges the researcher to continue strengthen the effectiveness.

A setup of diffuser is a choice to increase the efficiency that can be both wind and water turbine as found in the wind turbine study by Phillips *et al.* (2002) from the University of Auckland, New Zealand, Toshiio Matsushima *et al.* (2006) and Yuji Ohya *et al.* (2008). The study of Gerald and Van Bassel (2007) however indicates that not any power augmentation factor was more than 3, while as in the theory the power coefficient probably was 2.5; but the price of a diffuser is somewhat high.

David *et al.* (2008) were applying diffusers to water turbine that points to a 1.3 times increase of the output power of the bare turbine by installing a duct. Kirke (2005) shows in the examination of the axial flow turbine that a slotted duct installed in a towing tank tells to increase 70% of the output power if compared to a bare turbine. Grant (2005) reported that the ducted turbine was capable to pay a double load of the duct uninstalled turbine.

In addition, several countries, Canada, Ireland, England, U.S.A., Australia, and Portugal, have been developing water turbines for electricity, which are all in process, for

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examining the model mechanics, and for commerce.

Although the capacity of water current at low flow velocity, used as the energy source, is seldom applied to a water turbine, this article means to study functions and performance of a diffuser as to be the output power accelerator of horizontal axis water current turbine at low flow velocity, in order to be applied in the Northeast of Thailand that has two main rivers, Moon and Chii. The velocity of the water current is between 0-1.3 m/s, which is transformed into a two dimensional system by computational fluid dynamic (CFD). The attractive factors are the effect of diffuser angle, maximum augmentation factor, and rotor power coefficient due to the use of the diffuser design for a water current turbine.

2. Materials and Methods

2.1 One dimensional analysis

The one dimensional analysis is based on van Bassel (2007)

1) Empty diffuser case

From Figure 1 the surface of the diffuser outlet will be the referring point, front and back space of diffuser equals atmospheric pressure (P_0). The Bernoulli equation shows that the total pressure equals

$$P_{tot} = P_0 + \frac{1}{2}\rho V_0^2 = P_1 + \frac{1}{2}\rho V_1^2 = P_3 + \frac{1}{2}\rho V_3^3 = P_0 + \frac{1}{2}\rho V_e^2 \tag{1}$$

From the continuity equation the coherence between the inlet velocity (V_1), outlet velocity (V_3), and diffuser area ratio (β) is

$$V_1 = \beta V_3 \tag{2}$$

$$V_3 = \gamma V_0 \tag{3}$$

2) In terms of installed the rotor turbine:

$$V_3 = \gamma(1-a)V_0 \tag{4}$$

$$V_1 = \beta\gamma(1-a)V_0 \tag{5}$$

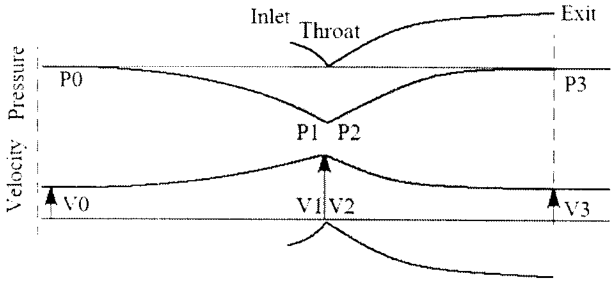


Figure 1. Relationship between pressure and velocity within the empty diffuser

The axial induction factor a is defined as $a = (V_0 - V_3)/V_0$, rotor power coefficient $C_{P,R}$ is defined as $C_{P,R} = \beta\gamma 4a(1-a)^2$, power coefficient at diffuser exit $C_{P,exit}$ is defined as $C_{P,exit} = \gamma 4a(1-a)^2$, total thrust coefficient $C_{T,T}$ is defined as $C_{T,T} = \beta\gamma 4a(1-a)$, and thrust coefficient of diffuser $C_{T,D}$ is defined as $C_{T,D} = C_{T,Total} - C_{T,R} = (\beta\gamma - 1)4a(1-a)$.

2.2 Computational fluid dynamics

Computational Fluid Dynamics (CFD is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. Computers are used to perform the calculations required to simulate the interaction of liquids or gases with surfaces defined by boundary conditions. There are three main processes – pre-processing, calculation processing, and post-processing. Here the Fluent 6.3 commercial code 2 dimensions with the finite volume method was used.

Governing equation

In this study, the Reynolds-Average-Naviaers–Stokes (RANS) equation is considered with renormalization group $k-\varepsilon$ turbulence model, which are indicated in Equation 6 to 11.

Continuity:

$$\frac{\partial}{\partial x_i}\left(\overline{\rho u_i}\right) = 0 \tag{6}$$

Momentum:

$$\frac{\partial}{\partial x_j}\left(\overline{\rho u_i u_j}\right) = -\frac{\partial \bar{p}}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu_t\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial \bar{u}_l}{\partial x_l}\right)\right] + \frac{\partial}{\partial x_j}\left(-\overline{\rho u_i' u_j'}\right) \tag{7}$$

In Equation 6 and 7 $\bar{p}$ is the mean pressure, $\bar{u}$ is the mean velocity, μ is the molecular viscosity, and $-\rho u_i' u_j'$ denotes the Reynolds stress. To correctly account for turbulence, Reynolds stress is modeled utilizing the Boussineq hypothesis to relate the Reynolds stress to mean velocity gradients within the flow. The Reynolds stress is defined as:

$$-\overline{\rho u_i' u_j'} = \mu_t\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right) - \frac{2}{3}\left(\rho k + \mu_t \frac{\partial \bar{u}_i}{\partial x_i}\right)\partial_{ij} \tag{8}$$

where μ_t is the turbulent viscosity and k is the turbulent kinetic energy. For k-ε in the turbulence model the turbulent viscosity is computed through the solution of two transport equations for turbulent kinetic energy and turbulence dissipation rate ε_t. The RNG transport equations are

$$\frac{\partial g}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}\left(\rho k \overline{u_i}\right) = \frac{\partial}{\partial x_j}\left[\alpha_k \mu_{eff}\frac{\partial k}{\partial x_j}\right] + G_k + G_b - \rho\varepsilon - Y_M + S_k \tag{9}$$

$$\frac{\partial}{\partial t}(\rho\varepsilon) + \frac{\partial}{\partial x_i}\left(\rho\varepsilon\overline{u_i}\right) = \frac{\partial}{\partial x_j}\left[\alpha_k \mu_{eff}\frac{\partial \varepsilon}{\partial x_j}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}\left(G_k + C_{3\varepsilon}G_b\right) - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} - R_\varepsilon + S_\varepsilon \tag{10}$$

$$R_\varepsilon = \frac{C_\mu \rho \eta^3 (1-\eta/\eta_0)}{1+\beta\eta^3}\frac{\varepsilon^2}{k} \qquad (11)$$

Computational conditions

The domain of the flow problem will cover diffuser and turbine area that are specified as wall and porous jump condition. The inlet boundary is set as the uniform flow velocity, the outlet boundary is set as outflow, top wall is as moving (slip) wall instead of volume of fluid (VOF) model, because of less time for calculation and acceptable accuracy, and the bottom wall is set as axisymmetric shown in Figure 2 and 3. Domains will be drawn in the Gambit program before been computerized by Fluent 6.3. Problem domains will be separated by quadrilateral grids into approximately 11,000 cells. Anyhow, grids will be dense around diffuser wall and turbine area.

The study sets the flow as axisymmetric steady flow it is segregated solver, whereas the turbulence model is a RNG *k-ε* model. The standard near wall function was chosen for the near wall treatment method with 10^{-6} of the convergence criterion. Sizes of the diffuser are unchanged but the diffuser angle shown in Figure 3 was changed from 0-90°. The porous medium will be from Darcy's Law and an additional inertial loss term with the equation As following:

$$\Delta p = \left(\frac{\mu}{\alpha}v + C_2\frac{1}{2}\rho v^2\right) \qquad (12)$$

where μ is the laminar fluid viscosity, α is the permeability of the medium, C_2 is the pressure-jump coefficient, υ is the velocity normal to the porous face, and Δm is the thickness of the medium.

3. Results and Discussion

3.1 Simulation results

Y^+ check:

In order to set the fineness of partition of the grid the refinement factor equals and when Re>100,000, the flow regime is turbulent and for the standard wall functions the proper Y^+ value is >30. From Figure 4 Y^+ of the diffuser wall values are from 26 to 398.

The evaluation of grid and Reynolds numbers per domain is split into 11,000 and 7,100 quadrilateral cells and the calculated Reynolds number is at 1,800,000 and 2,400,000, respectively. Reynolds number was defined as VD/υ when V is the axial velocity in m/s, D is the diameter of the diffuser and υ is the kinematic viscosity of water. Its result are an increased velocity (V_1/V_0) and a pressure coefficient (C_p) that is slightly different as shown in Figure 5 and 6, which will be cited later.

Flow inside the Diffuser

The results show that the differential pressure between upstream, in front of the diffuser, and downstream, at the end of the diffuser, increase when the diffuser angle is increased as shown in Figure 6a. The velocity of the water at the throat therefore is increasing varying with an increase of

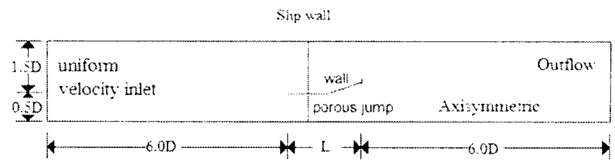


Figure 2. Domain of the problem

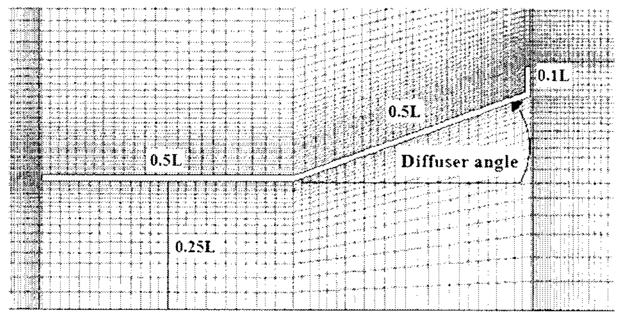


Figure 3. Diffuser dimension and grid system

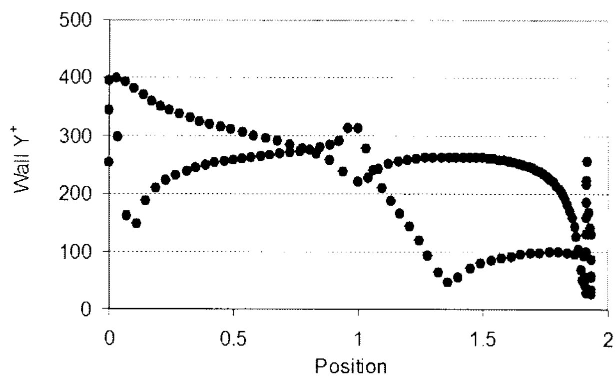


Figure 4. Y^+ of diffuser wall.

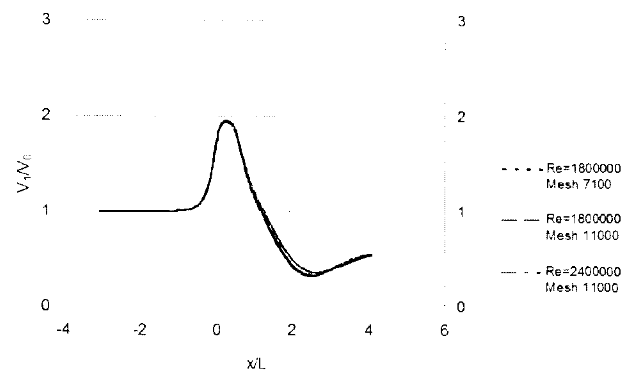


Figure 4.1 V_1/V_0 at axial diffuser.

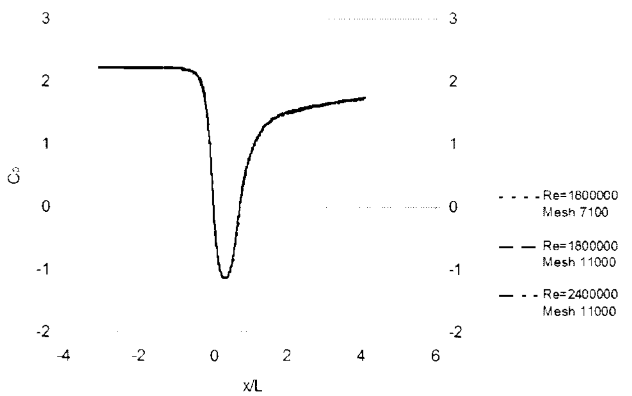
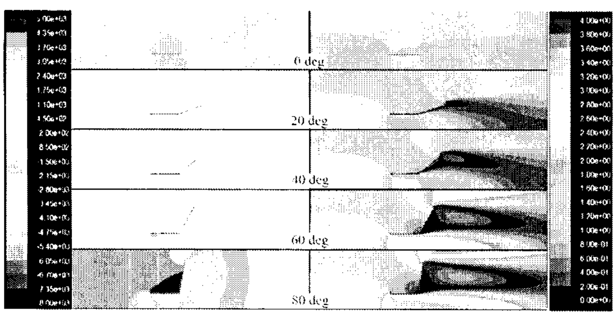


Figure 5. Value of C_p at axial diffuser.



(a) Static pressure (pascal) (b) Velocity (m/s)

Figure 6. Velocity (a) and pressure contour (b) of the empty diffuser.

the diffuser angle as shown in Figure 6b. However, the flow pattern can be divided into two cases: thefirst group is when the diffuser angles are between 0 and 20 degrees, which are the reasons for the increase in velocity at the throat because the pressure at the back of the diffuser becomes negative pressure due to the diffuser angle as shown in Figure 6a. The fluid flow at the throat will try to maintain its flow condition and accelerated through diffuser and the maximum speed is in the diffuser as shown in Figure 6b. The other group is the case of higher degrees, 40, 60 and 80 degree, even though the axial exit velocity does not decrease but the recirculation occurred at the exit of the diffuser. This recirculation also caused of lower pressure, then fluid in diffuser try to decrease pressure to exit value and fluid is speed up inside. That all results agree with Ken-ichi Abe, Yuji Ohya, 2004

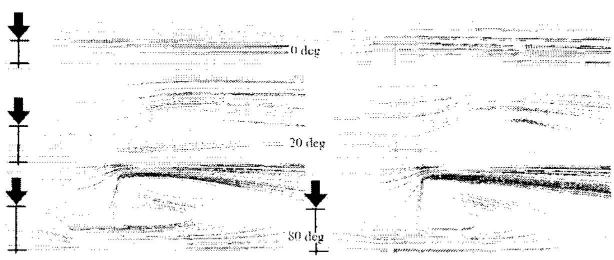
When rotor turbine was installed in diffuser. Equation (12) used to find out load of rotor. The 1st term is assumed to be zero. Maximum turbine power coefficient from Betz theory is 0.59 when induction factor (a) is 1/3, then C_2 equals 1333 /m at porous medium 0.0015 m thickness.

The results of Simulation 2D show streamline, at the angle of diffuser at 0°, 20°, and 80°, of empty diffuser and diffuser with 0.59 Cp of rotor turbine as shown in Figure 7a) and 7b), respectively. The increasing angle of diffuser shows the increasing of effective area. Even though when the rotor was installed, this area is not much change. This is reason of the velocity increased in the diffuser and more recirculation at exit of duct. However when the rotor turbine is installed, the flow show the increasing of recirculation with increasing diffuser angle.

The relation of velocity inside diffuser also show in the results of velocity plot on x -axis with different diffuser angle as shown in Figure 8. These results confirm all previous results that the velocity inside diffuser increases when the diffuser angle increases.

3) Diffuser augmentation, $\beta\gamma$

The results show diffuser area ratio, (β) Back pressure velocity ratio, (γ), Diffuser augmentation ($\beta\gamma$), VS Diffuser angle. β increases up to approximately 1.75 at 20 degree and then decreases to 1.0 at 50 degree, while γ gets increasing when the angle of diffuser increases as shown in Figure 9. It means that there's negative back pressure at the exit of the diffuser as seen in Figure 10. But the multiplication of β and γ is up. Therefore, it can be defined as γ significantly effects on diffuser augmentation ($\beta\gamma$) while β will be important if its angle is less than 20°



(a) (b)

Figure 7. Water streamlines of diffuser (a) without and (b) with 0.59 Cp of rotor turbine at 0, 20, and 80 degree.

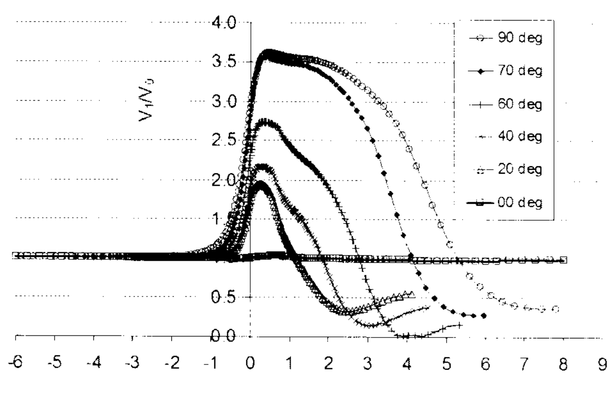


Figure 8. Relation between V_1/V_0 at different points on the x-axis direction to angle of the empty diffuser.

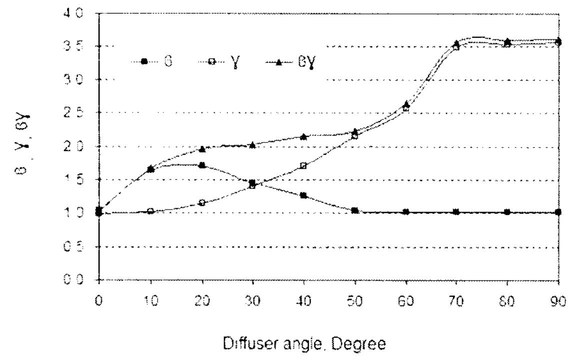


Figure 9. Relation of the diffuser area ratio, (β), back pressure velocity ratio, (γ), and diffuser augmentation, ($\beta\gamma$) to diffuser angle.

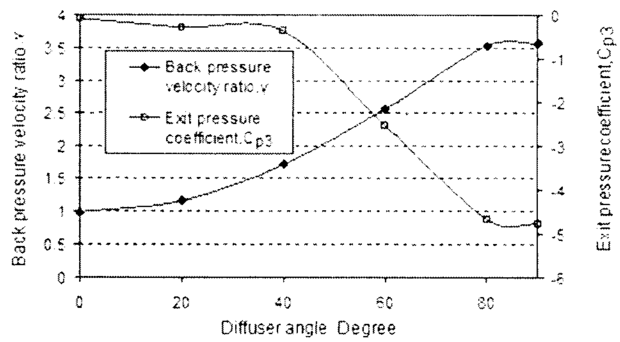


Figure 10. Relation of back pressure velocity ratio, (γ), and exit pressure coefficient, C_{PExit}, to diffuser angle.

4) Axial flow

The results also show From Figure 11 we can see that water speed up strike to rotor with diffuser compare to uninstall or installation of 0 degree diffuser. When V_1/V_0 increased according to angle of diffuser, pressure drop across rotor of turbine increased too. This show system can produce more power when more angle of diffuser was installed to rotor

5) Thrust loading coefficient

Figure 12: to widen angle of diffuser causes diffuser augmentation be higher; while thrust forced toward diffuser is obviously getting up between the phase of 0-20° and 50-70° but slightly influence on thrust coefficient of rotor. It can be defined as if we build diffuser with the more degree in order to keep energy as much as we require, durable structure is needed for the increasing thrust.

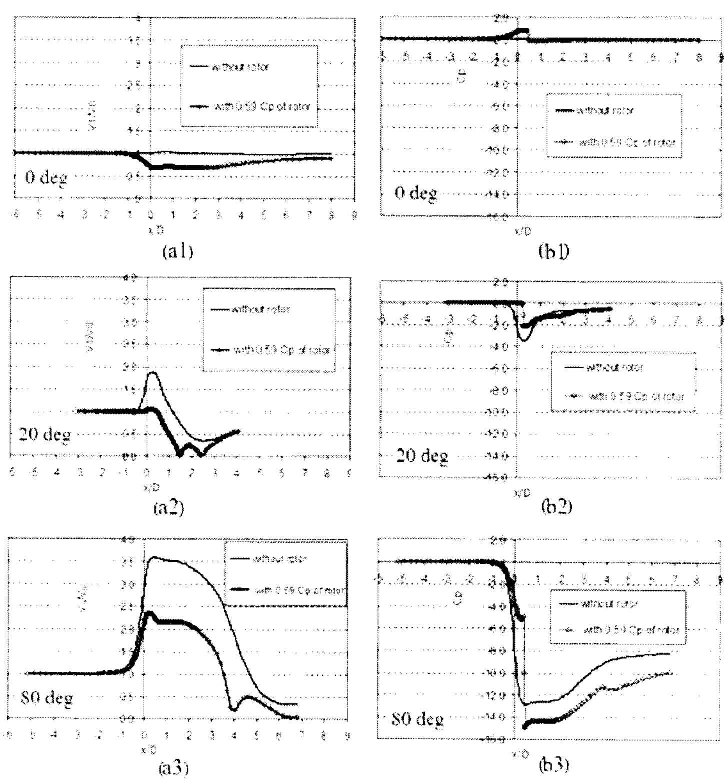


Figure 11. Velocity (a) and pressure coefficient (b) at axis of diffuser with and without rotor turbine with 0, 20, and 80 degree of the diffuser.

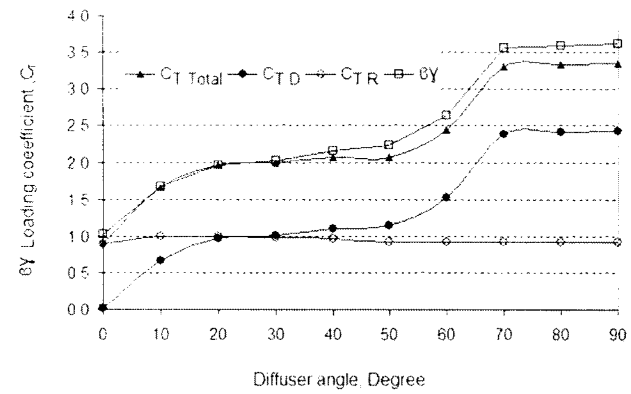


Figure 12. Relation of disk loading coefficient, $C_{T\,Total}$, $C_{T,D}$, $C_{T,R}$, and $\beta\gamma$ to diffuser angle, in degree.

6) Rotor power coefficient

Figure 13: It shows the Rotor power coefficient and diffuser augmentation, $\beta\gamma$ in case of axial induction factor, $a = 1/3$. We will see that the Maximum rotor power coefficient is 2.14 at 90 degree, minimum is 0.59 at 0 degree (We supposed it is the ideal turbine). We can say that diffuser augmented rotor power 3.62 times compared to system without diffuser

7) Validation of model

To validate the model simulation, 1.1 meter diameter 20 degree of diffuser was constructed and test in natural flow channel. Velocity of free upstream and middle of diffuser was collected every 20 second by paddlewheel flow sensor IP101 series. It was found that at mean free stream in front of diffuser 0.90 m/s we got 1.55 m/s inside of diffuser. We can say that Diffuser augmentation is 1.72 compare to the simulation result 1.96 or 14% different.

4. Concluding remark

Widening degree of diffuser causes more augmentation of V_i/V_0 which will be rapidly growing during the phase 0-20° and 50-70°. If the degree approximately equals 20°-50°, the augmentation will not change much; while the angle is about 70°-90° V_i/V_0 will be fixed. Thrust toward rotor will be steady if the augmentation is increased; where as thrust toward diffuser will be higher similarly. So, before contouring it's necessary to evaluate thrust. The effective factors towards V_i/V_0 include Diffuser area ratio, (β) and Back pressure velocity ratio (γ) that the latter one indicates it's increasing according to degree of diffuser which is good to performance of diffuser angle. At the same time β will be lower if the angle degree is more than 20° and will 1 as approximation when the degree is up to 50°. Via the study the diffuser augmentation will reach the maximum rate at 3.62 when the angle degree equals 90° and when the angle degree is about 20°- 50° the maximum rotor power coefficient twill be about 2.14

The above study aims at studying single factor that is diffuser angle. Still, there are many important factors needed further studying such as height of flange, length of diffuser and installing technique and etc.

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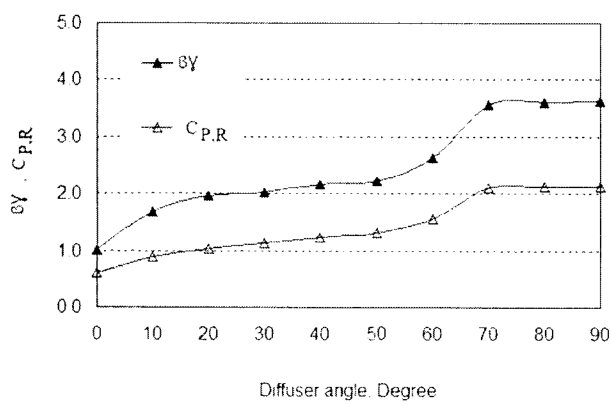

Figure 13. Relation of rotor power coefficient, $C_{P,R}$, and diffuser augmentation, $\beta\gamma$, to diffuser angle, in degree, in case of $a = 1/3$.

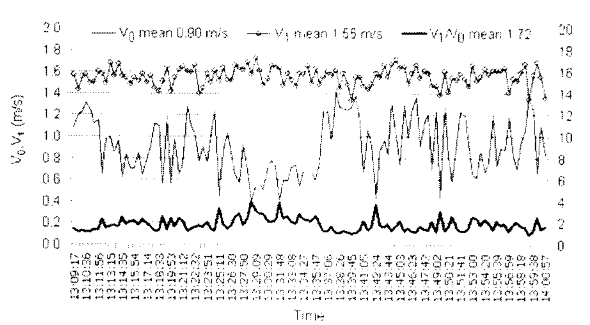

Figure 14. Diffuser without rotor turbine test result.

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Symbols:

a	Axial induction factor
α_k, α_ε	Inverse effective Prandtl numbers of k and ε consequently
β	Diffuser area ratio
$\beta\gamma$	Diffuser augmentation
C_p	Pressure coefficient
C_{pi}	Pressure coefficient at location
$C_{P,R}$	Rotor power coefficient
$C_{P,exit}$	Power coefficient at diffuser exit
$C_{T,D}$	Thrust coefficient of diffuser
$C_{T,Total}$	Total thrust coefficient of diffuser plus rotor
$C_{T,R}$	Thrust coefficient of rotor
$C_{1\varepsilon}$, $C_{2\varepsilon}$, $C_{3\varepsilon}$	Constant values
ε	Dissipation rate
G_k	Kinematic energy of mean velocity flow
G_b	Kinematic energy of buoyancy flow
γ	Back pressure velocity ratio
k	Turbulence kinetic energy
P_i	Pressure at location i
μ	Molecular viscosity
V_i	Velocity at location i
$\overline{x}$	Mean of x
Y_M	Contribution of the fluctuating dilatation in compressible turbulence to the overall dissipation rate