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Park, Young-Ju
Dept. of Fire & Emergency Management, Kangwon National University

Lee, Si-Young
Professional Graduate School of Disaster Prevention, Kangwon National University

Lee, Hae-Pyeong
Dept. of Fire & Emergency Management, Kangwon National University

Baek, Min-Ho
Dept. of Fire & Emergency Management, Kangwon National University

他

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Study on Fire Identification using Combustion Pattern Analysis of Pine Trees According to Climate Change in Korea

Young–Ju PARK[1], Si–Young LEE[2], Hae–Pyeong LEE[3], Min–Ho BAEK[4] and Shoji OHGA*

Laboratory of Forest Resources Management, Division of Forest Environmental Sciences,
Department of Agro–Environmental Sciences, Faculty of Agriculture,
Kyushu University, Fukuoka 811–2415, Japan
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This study monthly combustion tests were conducted on pine green leaves during June 2008 ~ May 2012 (4 years) for combustion pattern analysis of forest fires according to climate change in Korea. As result of research, fuel humidity of 75~178% was shown for 4 years in which much difference was shown according to climate. Period of frequent forest fires with high risk was shown to be in April and November, and it was shown that influence of fuel humidity was shown. Especially, April showed pattern of relatively higher risk of forest fires than October and range of auto ignition temperature was 270~355°C in which temperature difference of 85°C was shown according to climate change.

Total heat release was shown in range of 11~72 MJ/m^2 for 4 years, as April showed 41~56 MJ/m^2 and November showed 21~33 MJ/m^2 that April which had low fuel humidity showed relatively high heat release. Total smoke release was shown in range of 159~951m^2/m^2 for 4 years, as April showed 311~951 m^2/m^2 and November showed 246~322 m^2/m^2. Therefore, it could be known that April relatively releases more smoke than October. For carbon release, CO showed 1.6586~26.1460 g range and CO_2 showed 36.412~100.01 g range for 4 years and this concentration of combustion product has severe change by season that high release of CO 및 CO_2 is shown in April through May.

Key words: Fire identification, fire pattern, wildfire research, climate change, pine tree, combustion

INTRODUCTION

There are various causes of forest fires such as national tradition, habit, cultural development, and level of economic development, and the properties are also very different that it is very important to know those causes to prevent forest fires. Also, existence of combustibles, supply of oxygen, and ignition are required energy that affect risk of forest fires. However, source of fire which is required in ignition is the direct cause of forest fires. Forest stand condition, ground condition, and meteorological factors are indirect causes. Especially, there is large relation with quantity of water content of combustibles within forests. Meteorological factors, thus precipitation, humidity, wind, temperature, and insolation affect water content and there is deep relation with season and time in meteorological factors with much difference. Also, relation between water content of combustibles within forests and possibility of forest fires had deep relevance with relative humidity within air and water content of combustibles (Kang J. Y. *et al.*, 2002).

Approximately 78% of annual forest fires in Korea occur between March ~ May when relative humidity is the lowest in which risk is high according to relative humidity by spreading fires and various fire forms and patterns are shown according to types and form of fuel (Lee S. Y. *et al.*, 2001). Also, April had markedly low percentage of water content that ignition to show relatively slow progress

Adequate knowledge on forest fire form is essential in investigating ignition points in fire identification. Forest fires start small burning in blackening form, gradually proceeds, and the size increases as it quickly progresses. When turning into a crown fire, it spreads as it flies (WCDH, 2005). As activity of forest fires are affected by weather, fuel, and topography, forest fires leave clear burnt traces and characteristics showing direction of progress. Various types of traces during forest fires indicate ignition points and trace of only one area is not enough. Directions of flame progress in several areas must be investigated and back tracking until all traces gather to an ignition point is required. For that, combustion pattern data of combustibles influencing various pattern formation must be used.

Combustion pattern must be carefully used when investigating ignition points of forest fires in which scientific data is fundamentally required as interpretation ability is most important. Accurate combustion pattern interpretation is an essential factor reenacting fire scenes and becomes the only visual evidence after the fire is extinguished (Lee C. W., 2007). Also, physical characteristics of forest combustibles is essentially required to

[1] Dept. of Fire & Emergency Management, Kangwon National University, Samcheok–Si, Gangwon–Do 245–711, Republic of Korea
[2] Professional Graduate School of Disaster Prevention, Kangwon National University, Samcheok–Si, Gangwon–Do 245–711, Republic of Korea
[3] Dept. of Fire & Emergency Management, Kangwon National University, Samcheok–Si, Gangwon–Do 245–711, Republic of Korea
[4] Dept. of Fire & Emergency Management, Kangwon National University, Samcheok–Si, Gangwon–Do 245–711, Republic of Korea
* Corresponding Author (E–mail: ohga@forest.kyushu–u.ac.jp)

prepare scientific basis data and heat transfer, flame spreading, and flame speed provides information on exposed surface or change of outer appearance of material during the fire.

Therefore, data collection in scene during forest fire identification is not easy in which complex combustion environment is provided. In this study, thermal index characteristic data required in combustion patter analysis according to relative humidity to fire spreading and route of crown fires is to be provided subject to pine trees in Korea.

MATERIALS AND METHODS

1. Selection of Fuel and Combustion Test

Combustion test was conducted from June 2008~May 2012 (4 years) for combustion pattern analysis according to climate change. Pine tree which is most vulnerable to forest fires in Korea were selected as fuel and green leaves were extracted to be used in tests. Percentage of water content of combustibles were measured before the combustion test and percentage of water content was measured according to ASTM D 2016 standard (ASTM 2004 ; Kim H. J. *et al*., 2004). For measurement methods, 200 g was quantified, dried in a dryer in 105˚C, and weight was measured every 4 hours until there was no change of weight. The average value of 3 repeated measurement results were used as the result value.

Japanese company Kuramochi's group type ignition temperature tester (KRS–RG–9000 (Hong, Y. M., G. S. Jung 1992) and England company Fire Testing Technology's Dual cone calorimeter (ISO 5660–1, 2002) was used. Standard test method was used as main method to determine ignition risk of fuel and flashing point, ignition point, heat release speed, flame spreading, and flame were observed in which standard test was used to assess relative fire risk (NFPA 2008). Regarding specific test conditions are shown in Table 1.

2. Combustion Experiment

For combustion pattern analysis according to climate change, ignition characteristic, caloric value characteristic, and combustion product characteristic tests were conducted for 4 years during June 2008~May 2012. Ignition is behavior related to the start of combustion and is defined as the point where heat occurrence speed and spreading speed shows equilibrium in speed control mechanism. Auto ignition temperature which is the temperature when auto ignition temperature proceeds, was measured and flame duration time was analyzed through TTI (Time to ignition) and F.O. (Flame out) measurement.

THR (Total heat release) is an accumulated value of integration of heat release rate which is expressed as a function on time by specimen surface. Also for combustion products, characteristics of CO, CO_2, and residue were analyzed and average value of 3 repeated measurement results were used as the result value.

Change occurring on material by fire must be recognized to distinguish combustion pattern. This change called effect of fire occurs on the inside and surface of combustibles and can be observed or measured by the naked eye (NFPA 921, 2008).

RESULTS AND DISCUSSION

1. Fuel Humidity Characteristics

Figure 1 shows the percentage of water content curve of pine green leaves according to climate change in Korea. Characteristics of percentage of water content curve of pine green leaves receives direct influence of relative humidity and percentage of water content was shown low every March and April. Relative humidity is percentage of water content included in air shown in percentage and showed to have direct influence on dryness of combustibles. As shown in Table 2, March ~ May shows dry weather in Korea and plants are in period of dormancy in this period that water content in fallen leaves, fallen branches, and hay is low that is becomes the cause the cause to increase risk of forest fires.

Also, this dry climate affects dryness of forest combustibles to have influence on combustion progress speed

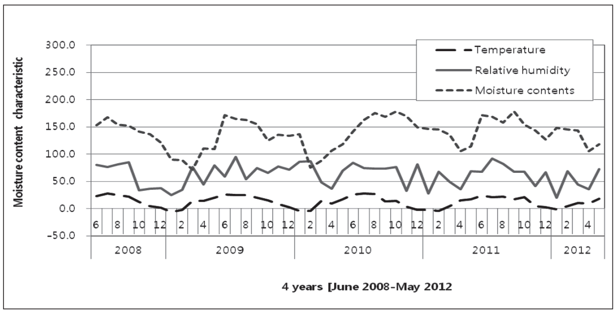

Fig. 1. Characteristics of percentage of moisture content of pine green leaves according to climate change.

Table 1. Test conditions of cone calorimeter and auto ignition temperature

Ignition temperature measurement		Dual cone calorimeter measurement	
Model	KRS–RG–9000	Sample holder size	100×100 mm
Method of measurement	group	Weight	50 g
Weight	20 mg	Heat flux	50 kW/m^2
Condition of material	green leaves	Test time	time until there was no more weight decrease
Waiting time of ignition	4 sec	Condition of material	living leaves

Table 2. Characteristics of ignition and heat caloric value of pine green leaves according to climate change

Yea	Month	Weather characteristic		Moisture contents[%]	Ignition characteristic			Calorific value
		Tempera ture(˚C)	Relative humidity(%)		Auto ignition temperature.(˚C)	ignition time (sec)	Flame duration time(sec)	Total heat release (MJ/m²)
2008	6	22.6	80	153.00	320	n	n	25.6
	7	27.5	76.8	168.00	285	n	n	72.4
	8	25.2	80.9	154.00	290	n	n	25.3
	9	21.7	85.5	152.00	300	n	n	28.2
	10	12.0	34	141.00	290	n	n	28.4
	11	4.9	36.4	137.00	300	n	n	32.6
	12	1.8	37.4	121.00	330	n	n	28.8
2009	1	–6.3	24.4	90.00	317	n	n	21.9
	2	–2.5	34.6	89.00	277	53	15	34.3
	3	14.3	76.4	71.00	280	61	27	32.4
	4	14.4	44	110.00	315	56	9	55.6
	5	19.7	79	109.00	303	45	6	54.8
	6	26.1	58.4	172.00	386	79	5	29.4
	7	24.8	94.4	165.00	343	n	n	20.5
	8	25.2	54.4	163.00	314	84	14	24.8
	9	20.1	74.1	154.83	310	n	n	44.3
	10	15.0	65.9	124.94	280	n	n	44.3
	11	8	77	135.56	285	301	71	21.3
	12	2.8	71.9	133.28	290	n	n	23.5
2010	1	–4.1	85.9	136.58	279	n	n	21.1
	2	–4.5	86.6	75.38	280	n	n	20.5
	3	14.4	47.9	88.40	310	50	60	18.5
	4	9.6	36.6	106.00	297	23	33	55.7
	5	17.4	70	118.00	290	43	8	29.4
	6	25.9	83.9	141.17	298	78	9	23.7
	7	28.2	74.4	162.45	301	n	n	21.6
	8	26.4	73.3	175.71	307	n	n	34.5
	9	13.0	73.9	168.93	347	n	n	19.2
	10	13.9	76.8	178.24	277	n	n	15.9
	11	3.6	32.5	169.2	298	108	13	12.0
	12	–2.6	80.8	148.9	305	305	57	13.1
2011	1	–2.7	28	146	345	n	n	24.1
	2	–4	67.8	145	270	n	n	22.2
	3	4.6	48.9	135.1	329	67	112	20.8
	4	14.7	35.8	105.2	345	76	124	41.3
	5	16.9	68.5	113.8	366	454	322	38.8
	6	23.7	67.8	171.5	331	82	3	18.3
	7	21.2	91.6	168.6	330	95	8	20.7
	8	21.5	81.9	158.2	310	n	n	26.2
	9	17.1	67.4	178.5	310	n	n	24.4
	10	21.2	67.8	154.1	277	81	30	11.8
	11	4.6	40.9	143.6	301	190	13	24.6
	12	2.3	66.6	126.9	282	103	18	21.2
2012	1	–1.5	19.9	148.1	312	89	56	24.5
	2	4.7	68.9	145.2	305	107	55	16.9
	3	10	44.1	143.8	320	52	61	26.2
	4	9.5	36	105.80	344	68	122	41.9
	5	18.0	72	118.00	355	450	320	37.2

of forest fires and the condition of fuel humidity has direct influence on progress speed and combustion intensity of forest fires. Therefore, risk and period of frequent forest fires during the year were shown to be in early April and early October as shown in Table 2 and it was shown that April had relatively lower percentage of water content than October.

Fuel humidity for 4 years was shown in 75~178% range in which there was much difference of fuel humidity according to climate. However looking into April and October when risk of forest fires is high, percentage of water content of pine trees were 110.00%, 106.00%, 105.20%, and 105.80% in 2009, 2010, 2011, and 2012, respectively in April and percentage of water content of pine trees was 137.00%, 135.56%, 169.20%, and 143.60% in 2009, 2010, 2011, and 2012, respectively in October. Therefore, this difference of percentage of water content of forest combustibles are caused by high temperature, low humidity in air, and wind in which they can become factors that change direction of flames to combustion pattern when obstacles are met during forest fired.

2. Ignition characteristic index

2.1 Auto ignition temperature characteristics

Auto ignition temperature curve of pine tree green leaves according to climate change in Korea are shown in Figure 2. Auto ignition temperature is the temperature where ignition starts as combustibles reach ignition temperature with no exterior ignition source. Auto ignition temperature range was shown to be between 270~355°C and showed a maximum difference of 85°C according to climate change. Looking into April and October when risk of forest fires is high, characteristics of monthly auto ignition temperature of pine trees were 315°C, 297°C, 345°C, and 344°C in 2009, 2010, 2011, and 2012, respectively in April and auto ignition temperature of pine trees was 300°C, 285°C, 298°C, and 301°C in 2009, 2010, 2011, and 2012, respectively in October.

Also as shown in Table 2, April and October which has relatively higher percentage of water content than June, July, August had tendency of slightly higher auto ignition temperature and June, July, August rather showed low auto ignition temperature. This is considered to be because moisture makes accumulation of heat convenient when appropriate moisture is included compared to dry condition and therefore auto ignition easily occurs.

These characteristics of auto ignition show flameless smoldering with gradual smoke proceeding from combustible surface in which low auto ignition temperature means that risk of auto ignition becomes that much higher. Also, auto ignition has auto ignition temperature form that combustion timidly continues when temperature is low or oxygen is lacked until ignition in which combustion gradually spreads inside combustibles and cannot be found for a long time as it can be progressed into flaming if enough oxygen is supplied or temperature increases (Lee S. H., 2009).

2.2 Characteristics of Ignition time and flame duration time

Ignition time curve of pine tree green leaves according to climate change in Korea are shown in Figure 2. Looking into April and October when risk of forest fires is high, characteristics of ignition time of pine trees were 56 sec, 23 sec, 76 sec, and 68 sec in 2009, 2010, 2011, and 2012, respectively in April and ignition was no ignition, 601 sec, 108 sec, and 190 sec in 2009, 2010, 2011, and 2012, respectively in October. Ignition time receives direct influence of percentage of water content as percentage of water content of pine trees in April had range of 105~144% and October had range of 135~169% for April to show markedly low percentage of water content than October in which it is considered that ignition had relatively quickly proceeded. Quick ignition time makes flame spreading faster in the initial fire that it influences combustion patter.

Also, this difference of ignition not only affects percentage of water content, but also have influence on change of leaf structure and components by change of season, and ignition phenomenon such as difference of volatile components occurring during combustion (Hyun S. H. *et al*., 2003). Therefore, short ignition time means that combustion quickly proceeds that expansion of combustion can quickly spread during fires (Kang S. D. *et al*., 2002).

Looking into flame duration time after flaming ignition, it was shown that flame is maintained between 5 sec ~ 71sec and this is considered to be because radiant heat increases to increase fire spreading. Also, this characteristic of flame duration time can become beneficial data to estimate combustion routes in forest fire identification and can become basis data to recognize combus-

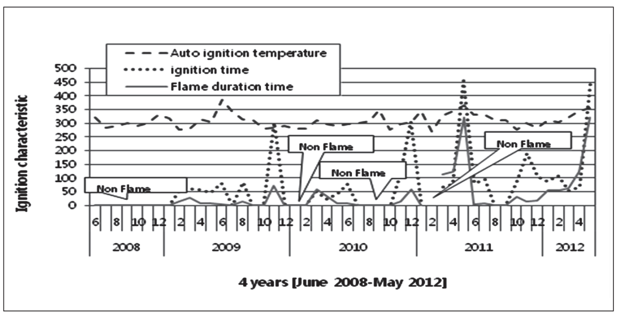

Fig. 2. Characteristics of ignition and flame duration time of pine green leaves according to climate change.

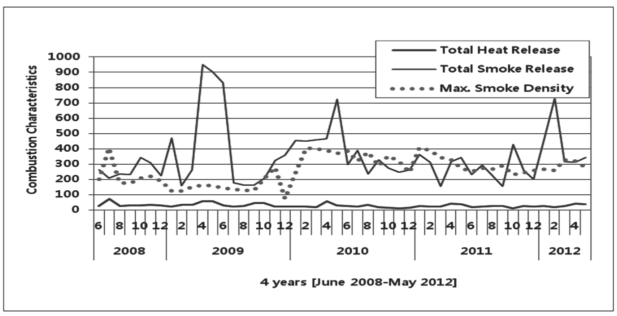

Fig. 3. Characteristics of THR and TSR of pine green leaves according to climate change.

Table 3. Characteristics of calorific heat and combustion products of pine green leaves according to climate change

Year	Month	Caloric value			Combustion product		
		Total smoke release(m^2/m^2)	Maximum smoke density(Ds)	Maximum Density time(Sec)	Residue(g)	Total CO release(g)	Total CO_2 release(g)
2008	6	263.7	202.3	780	0.4	2.7525	43.293
	7	207.2	405	565	0.1	3.3343	49.31
	8	235.2	176	892	0.7	2.6277	41.946
	9	231.0	175.5	959	0.5	2.4374	46.105
	10	343.2	207	844	0.5	2.2344	42.727
	11	308.6	218.4	1064	1.2	2.6794	43.266
	12	223.7	190.3	1028	0.3	2.6121	44.785
2009	1	470.3	124.2	1118	1.3	2.9169	48.341
	2	158.6	124.3	1200	2.9	2.4766	48.445
	3	263.6	149.7	1083	2	2.8851	49.409
	4	950.5	160.4	1045	0.3	2.5606	151.65
	5	904.9	157.2	1011	0	1.7713	159.77
	6	830	142.6	1023	0.9	4.0054	157.26
	7	178.8	133.8	1194	0.2	2.1418	36.412
	8	161.1	128.3	1196	1.4	2.7268	40.653
	9	160.7	126.8	1200	7.1	3.2801	46.039
	10	207.8	207.1	887	2.5	3.6578	52.711
	11	322.2	276.9	611	1.1	3.278	58.425
	12	358.8	73.48	1201	1.1	8.8635	58.279
2010	1	452.6	244.5	563	2.8	2.8066	46.514
	2	450.2	406	567	2.8	2.7794	45.949
	3	458.3	400	571	2.7	3.21	55.98
	4	467.2	387.8	573	2.6	5.7482	68.347
	5	721.9	368.3	561	1.3	9.7942	42.87
	6	296.6	383.4	457	0.1	20.307	92.403
	7	387.3	318.3	495	1.1	12.167	80.109
	8	236.3	376.4	443	0	2.6168	42.004
	9	326.9	289.4	503	0.7	18.551	112.07
	10	271.8	353.3	515	1.6	16.06	84.829
	11	245.6	316.4	518	1.1	20.547	91.362
	12	263.5	246	562	1.1	26.146	100.04
2011	1	363.8	407.9	569	1.1	9.0543	59.534
	2	311	388.5	587.3	2.2	12.659	77.09
	3	156.2	343.5	601	0.5	25.579	87.529
	4	313.9	325.6	660	0.1	4.6468	66.998
	5	343.2	273.5	565	0.2	1.6589	77.547
	6	232	250.6	587	1.4	8.8404	69.075
	7	294.6	275.3	572	0.3	10.372	68.833
	8	227.8	265.7	561	2.3	8.4542	60.369
	9	154.5	289.4	503	0.1	10.494	61.718
	10	428.6	230.6	537	0.1	20.831	79.29
	11	258.3	244.7	588	0.1	4.469	52.23
	12	201.8	260.1	643	0.3	5.2899	56.909
2012	1	460.7	264.4	600	0.1	2.7857	62.593
	2	732.4	260.1	643	0.1	5.4509	59.699
	3	315.6	325.6	660	0.1	5.2516	61.568
	4	311	320	660	2.5	5.75	68.111
	5	344	277	622	1.36	7.2012	51.2

tion pattern.

If flames last for a long time after ignition and reach a certain size, flames do not stay in the same intensity as before. Flames slowly spread, quicken, weaken, or grow by factors such as wind intensity, gradient, quantity of fuel, and obstacles. These changes are generally shown in index and shows the ignition point.

2.3. Characteristics of heat exposure index

Figure 3 shows total heat release, total smoke release, and total smoke density curves of pine green leaves according to climate change in Korea. Total heat release was shown in range of 11~72 MJ/m^2 during the 4 years. Looking into April and October when risk of forest fires is high, 55.6 MJ/m^2, 55.70 MJ/m^2, 41.3 MJ/m^2, and 41.9 MJ/m^2 was shown in 2009, 2010, 2011, and 2012, respectively in April and 32.6 MJ/m^2, 21.3 MJ/m^2, 12.0 MJ/m^2, and 24.6 MJ/m^2 was shown in 2009, 2010, 2011, and 2012, respectively in October. Therefore, heat release of 41~56 MJ/m^2 was shown in April and 21~33 MJ/m^2 was shown in October. Especially, it was shown that April which has high percentage of water content in fuel had relatively high calorific value. Specific values are shown in Table 3.

When forest fires in April with relatively high calorific values proceed into crown fires, fire loading increases to quicken fire spreading. The reason of this high calorific value is because thermal decomposition rapidly proceed in the initial combustion that large quantity of heat is released for main components such as C, H, S to be combined with oxygen. CO_2, H_2O, SO_2 are produced as combustibles are completely exhausted, surrounding temperature is increased by high calorific value to quicken heat spreading speed, and the quick heat spreading proceeds quick spreading of fire (Kim H. J. *et al.*, 2004).

Calorific value has much influence on damage as must as the length of combustion time of combustibles. Wide range of damage means that important combustibles had existed in the corresponding location and spreading of combustibles have important meaning in considering how fires were spreaded from other locations (NFPA, 2011). Also, forest combustibles of crown fires proceed in a V shape towards the direction of wind in which the fleet of the V shape has 20~40 m length as many fleets occur when proceeding into a large fire. Also when crown fire occurs in a surface fire starting at the tiptop, maximum temperature of the core reaches 1175°C showing very strong fire force of surrounding flame temperature of 1125°C, and combustion speed generally proceed 2~4 km an hour which can reach 15km an hour in strong wind (Kang J. Y. *et al.*, 2002).

Also, when fire loading is applied largely due to high calorific value from the flame point, heat and speed gradually grows to show typical effect that crown fire has on trees or bushes.

2.4. Characteristics of combustion product exposure index

Figure 3 shows the total heat release curve of pine green leaves according to climate change in Korea. Looking into total smoke release by climate, total smoke release was shown in 159~951 m^2/m^2 during the 4 years in which 950.5 m^2/m^2, 467.2 m^2/m^2, 313.9 m^2/m^2, and 311.0 m^2/m^2 was shown in 2009, 2010, 2011, and 2012, respectively in April and 308.6 m^2/m^2, 322.2 m^2/m^2, 245.6 m^2/m^2, and 258.3 m^2/m^2 was shown in 2009, 2010, 2011, and 2012, respectively in October. Therefore looking into the total smoke release in April and October when risk of forest fires is high, range of 311~951 m^2/m^{2}was shown in April and range of 246~322 m^2/m^2 was shown in October in which more smoke release was shown as it became closer to 2012. Also, it was shown that more smoke is released in April compared to October. Therefore more smoke release means that it can become a clue to making an index of soots after forest fires.

Maximum smoke density or total smoke release show similar tendency in which 2 peaks are shown in April and October. High maximum smoke density and quick maximum smoke density time means that smoke density reaches maximum value in short time and more than 10% of fuel in incomplete combustion of smoldering in combustion products are CO in which it can be fatal to the body as it is a very dangerous form of fire(Lee S. H., 2009) Specific values are shown in Table 3.

Figure 4 shows a curve of residue, total CO release, and total CO_2 release after combustion of pine trees according to climate change in Korea. Looking into residue in April and October, 0.3 g, 2.6 g, 0.1 g, and 2.5 g was shown in 2009, 2010, 2011, and 2012, respectively in April and 1.2 g, 1.1 g, 2.6 g, and 0.1 g was shown in 2009, 2010, 2011, and 2012, respectively in October. Therefore, it was shown that residue of 0.1~2.5 g was shown in April and 0.1~2.6 g was shown in October. There was no special tendency in this characteristic of residue, but concentration of combustion products severely varies by change of season in which it shows maximum value in April ~ May when forest fires frequently occur.

Looking into total CO release, range of 1.6586~26.1460 g was shown during the 4 years. Looking into characteristics of April and October when risk of forest fires is high, 2.5606 g, 5.7482 g, 4.6468 g, and 5.7500 g was shown in 2009, 2010, 2011, and 2012, respectively in April and 2.6794 g, 3.2780 g, 5.5470, and 4.4690 g was shown in 2009, 2010, 2011, and 2012, respectively in October. Therefore, it was shown that about 2.5606~5.7500 g CO was shown in April and 2.6274~5.5470 CO was shown in October. Looking into total CO_2 release,

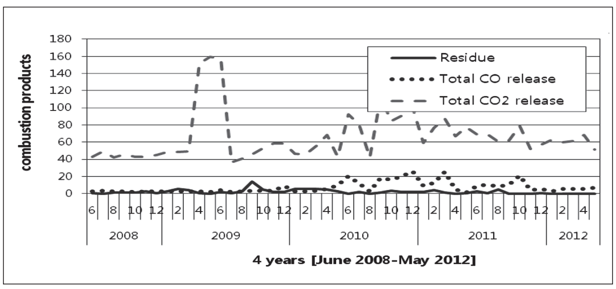

Fig. 4. Characteristics of combustion products of pine green leaves according to climate change.

range of 36.412~100.01 g was shown during the 4 years. Looking into characteristics in April and October when risk of forest fires is high, 151.65 g, 68.347 g, 66.998 g, and 68.111 g was shown in 2009, 2010, 2011, and 2012, respectively in April and 43.266 g, 58.425 g, 91.362 g, and 52.23 g was shown in 2009, 2010, 2011, and 2012, respectively in October. Therefore, it was shown that about 66.998~151.65 g CO was shown in April and 43.266~91.362 g CO was shown in October. Specific values are shown in Table 3. These combustion products make index of soots during forest fires and soots heading toward ignition point and soots piles on objects mean that it can become a better index. (WCDA, 2005)

CONCLUSION

This study monthly combustion tests were conducted on pine green leaves during June 2008~May 2012 (4 years) for combustion pattern analysis of forest fires according to climate change in Korea. Monthly combustion tests were conducted for 4 years to achieve the following conclusions required to interpret fire spreading routes and combustion patterns.

1) Fuel humidity of pine trees during the 4 years according to climate change were shown as 75~178% showing much difference of fuel humidity according to climate and was 105~110% in April and 135~169% in October when risk of forest fires is high. Also, it could be known that April has relatively lower percentage of water content than October. This level of percentage of water content can become a factor to change flame direction into the same combustion patter when obstacles are met during forest fires.

2) Range of auto ignition temperature was shown to be 270~355°C to have difference of 85°C according to climate. 315°C, 297°C, 345°C, and 344°C was shown in 2009, 2010, 2011, and 2012, respectively in April and 300°C, 285°C, 298°C, and 301°C was shown in 2009, 2010, 2011, and 2012, respectively in October. Therefore, it can be known that April and October has tendency of slightly higher auto ignition temperature than June, July, August when percentage of water content is relatively high.

3) Ignition time of 56 sec, 23 sec, 76 sec, and 68 sec was shown in 2009, 2010, 2011, and 2012, respectively in April and no ignition, 601 sec, 108 sec, and 190 sec was shown in 2009, 2010, 2011, and 2012, respectively in October. Therefore, April showed markedly lower percentage of water content than October that relatively quicker ignition was shown. Also, it could be found that flame duration after flaming ignition maintained between 5sec~71sec.

4) Looking into characteristic of heat release, range of 11~72 MJ/m^2 was shown during the 4 years. It could be known that calorific value of 41~56 MJ/m^2 was released in April and 21~33 MJ/m^2 was released in October. Especially, it was shown that April, which had high percentage of water content in fuel, had relatively high calorific value. It is considered that during forest fires in April with relatively high calorific value that proceed into crown fires have high fire loading that fire spreading quickly proceeds.

5) Looking into characteristic of total smoke release, range of 159~951 m^2/m^2 was shown during the 4 years. It could be known that total smoke release of 311~ 951 m^2/m^{2}was released in April and 246~322 m^2/m^2 was released in October. Also, it was shown that April showed relatively more smoke release than October. Maximum smoke density also showed identical tendency in which there were 2 peaks in April and October. Residue after combustion was shown to be 0.1~2.5 g in April, and 0.1~2.6 g in October in which no special tendency was shown.

6) As result of carbon release, range of 1.6586~26.1460 g was shown during the 4 years. CO was released with 2.5606~5.7500 g range in April and 2.6274~5.5470 g range in October. For total CO_2 release, range of 36.412~100.01 g was shown during the 4 years. It could be known that CO_2 release of 66.998~151.65 g was released in April and 43.266~91.362 g was released in October. This concentration of combustion products severely vary by change of season in which tendency of increasing CO and CO_2 release was shown in April ~ May when forest fires frequently occur.

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