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COMPOSTING OF OPIUM POPPY PROCESSING SOLID WASTE WITH POULTRY MANURE: EFFECTS OF AIRFLOW RATE ON COMPOSTING LOSSES

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Abstract

In this study, composting of opium poppy processing solid waste with poultry manure and rough sawdust with C/N ratio of 25 (65% opium poppy processing solid waste, 14% poultry manure, and 21% sawdust, dry basis) was conducted using fifteen-identical cylindrical stainless steel reactors, each of which has an effective volume of 100 L. The moisture content of initial mixture was 66%. Five aeration rates (aeration rates executed under set point temperature, Q_{min}= 0.5, 1.0, 1.5, 2.0, and 2.5 m^3/h) were applied with fan on/off time (min) of 5/25, 7.5/25, and 10/25. The experiment lasted for 7.79 days. In the experiment, the temperature, electrical conductivity (EC), pH, moisture, organic matter, oxygen (O_2) and carbon dioxide (CO_2) concentrations, total carbon and nitrogen contents were monitored. Dry matter loss, organic matter loss, carbon loss, and nitrogen loss were expressed as functions of Q_{min} and on/off times. Results showed that the highest losses occurred at the aeration rate of Q_{min}=1.5 m^3/h. Losses as functions of aeration rate with on/off time showed that the highest losses existed at the aeration rate of Q_{min}=1.5 m^3/h with on/off time (min) of 7.5/25-10.0/25.

Key words: *aeration, composting loss, opium poppy processing, poultry manure*

INTRODUCTION

Opium poppy (*Papaver somniferum* L.) is perhaps the earliest medicinal plant known to the mankind (Kapoor, 1995). Over 42 alkaloids have been isolated from opium poppy but only few are of major significance. These are morphine, codeine, the baine and papaverine, which have positive use in pharmaceutical preparations. In Turkey, traditionally cultivated specie is *Papaver somniferum* L. which is a single annual crop plant. Oil content of the seeds (50%) makes it useful for human consumption. Capsule, on the other hand is an important industrial crop due to its alkaloid content which are very important for medicinal purposes (TMO, 2011; Frick et al., 2007; Wijekoon and Facchini, 2012). Medicinal alkaloids are prepared from capsules in many countries including China (Mahdavi-Damghani et al., 2010). Opium poppy processing solid wastes (OPPSW) is produced when capsules processed to extract alkaloids. OPPSW is a functional feed material and has positive effects on milking cows and milking buffalos (İpek and Arslan, 2012). At the same time, this unique material is an important organic fertilizer substrate due to its organic material content. However, because of its trace amount of morphine content, it leads to environmental problems such as hygiene and odour problems. Afyon Alkaloids Plant in Turkey has a plant with a capacity to process 20,000 tons of unscratched opium poppy. Due to that, it has the capacity to meet nearly 30% of the world's legal drug consumption (Anonymous, 2016a). According to the Ministry of Agriculture report, in year 2015, 71,210 producers are paid for producing 30,730 tonnes of opium capsule (Anonymous, 2016b). Turkey has an important role in worlds' opium production. Processing of 1 tons raw opium poppy capsule results in 2.5 tons of OPPSW at the moisture content of 65% wet basis. The amount of wastes caused by livestock production is increasing and cause environmental problems. These wastes can be composted to produce a useful, economic and salable compost product. Aeration is one of the key component of a successful composting process (Hansen et al., 1989). The amount of aeration varies depending on the material used. For example, high-energy materials (animal manure) require more air supply, while leaf, straw, and other materials require less air for composting (Finstein and Hogan, 1993). In the composting process, the presence of a certain amount of oxygen in the environment accelerates the decomposition process. Once the aeration rate has been determined, it is necessary to choose how the aeration is supplied to the compost matrix. This study involves composting of opium poppy processing solid wastes with poultry manure and rough sawdust. The study was conducted to determine the effects of aeration on composting loss (dry matter loss, organic matter loss, carbon loss, and nitrogen loss).

MATERIALS AND METHODS

This study involved OPPSW, Poultry Manure (PM) and Rough Sawdust (RS). The OPPSW was received from Afyon Alkaloids Factoryin Afyon province. PM was received Gürelli farm in Isparta province. RS was maintained from the local sawmill. The main characteristics of the three raw materials (OPPSW, PM, and RS) are reported in Table 1. Values reported are on a dry weight basis except for moisture content which is on a wet weight basis. The proportions of OPPSW, PM, and RS in the compost mixture based on dry weight basis were 65.38%, 13.99, and 20.63, respectively. Fifteen-identical cylindrical stainless steel reactors, each of which has an effective volume of 100 L with the inner diameter of 47.3 cm and height of 57.0 cm were used in the experiment. They had perforated stainless steel floors with a hole size of 4 mm (diameter) at 13 cm height up from the bottom and 40 percent openings to provide a plenum for air distribution under the compost. K type thermocouples with a diameter of 3 mm and 35 cm length are inserted into each composting reactor equipped with three ports to facilitate temperature at three levels of 10, 27, and 44 cm above the perforated floor. Control of aeration fans, solenoid valves and pumps in the laboratory composting systems as well as data acquiring and logging were performed by a PLC (Schneider M258) (Figure 1).

Table 1. Initial physical and chemical properties of feedstock and composting mix used in the experiment

	OPPSW	PM	RS	Mix
Moisture,%	35.52±1.60	72.42±0.44	6.1±0.01	66.10±0.86
Organic matter, %	55.39±0.27	70.52±0.31	99.18±0.05	76.00±0.81
EC, dS/m	2.21±0.01	11.48±0.02	3.9±0.14	2.99±0.15
pH	8.78±0.05	5.22±0.00	5.7±0.14	8.70±0.10
Total C, %	33.00±0.05	35.41±0.08	48.60±0.10	38.04±0.24
Total N, %	0.88±0.06	5.87±0.03	0.13±0.02	1.52±0.02
C/N	37.5	6.03	373.85	25.11±0.51

Figure 1. Composting reactors

Air flow supplied into the reactors by fans (0.25 kW) is measured by a hot wire anemometer (QVM62.1 Siemens) and the results of measurement are transmitted to the PLC unit. Compost temperature was controlled through airflow manipulation based on temperature feedback control. Temperature is the controlled variable and aeration rate is the manipulated variable (Ekinci et al., 2004). Fans are operated with on/off mode when the compost temperature (T) is less than or equal to set point temperature (T_{sp}) to regulate airflow and to allow temperature increase. This stage is characterized with on/off time and volumetric airflow rate (Q_{min}, m^3 h^{-1}) to meet minimum requirements for oxygen and air movement. Q_{max} was continuously applied by the controller to cool down compost mass when $T>T_{sp}$. (Figure 2). Aeration rates and on/off values used in the experiment are listed in Table 2.

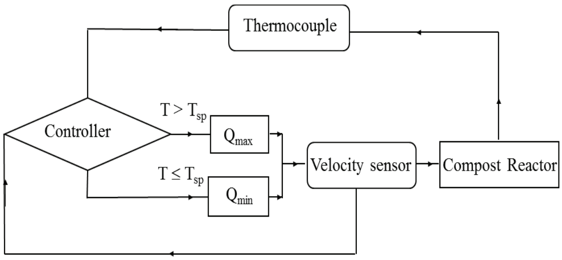

Figure 2. Control strategies for temperature control (Rutgers strategies) in composting reactor

Table 2. Aeration rates and on/off values used in the experiment

Q_{min}= (m^3/h)	0.5			1			1.5			2			2.5		
T_1= Duration of on-time for aeration (min)	5	7.5	10	5	7.5	10	5	7.5	10	5	7.5	10	5	7.5	10
T_2= Duration of off-time for aeration (min)	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
$\xi=T_1/T_2$	0.2	0.3	0.4	0.2	0.3	0.4	0.2	0.3	0.4	0.2	0.3	0.4	0.2	0.3	0.4
Reactor No	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15

Duplicate samples were taken from each reactor at the beginning, right after remixing, and at the end of experiment. Moisture contents of fresh samples were determined after the samples were dried at 70±5°C for 3 days, and organic matter content of dry samples was analyzed after incinerating the samples at 550°C as recommended by the US Department of Agriculture and the US Composting Council (USCC, 2002).pH and EC of the fresh samples were extracted by shaking at 180 rpm for 20 min at a solid: water ratio of 1:10 (w/v), and measured using pH and EC meters (Models WTW pH 720 and WTW Multi 340i), respectively. Total C and N content were analyzed using the elemental analyzer (Vario MACRO CN Elemental analyzer).

Dry mass loss (DML), organic mass loss (OML), carbon loss (C-loss), and nitrogen loss (N-loss) were calculated based on initial and final values of dry matter and their corresponding concentrations.

$$\text{DML (\%)}=\left(1-\left[\frac{m_d(\theta)}{m_d(0)}\right]\right)100 \qquad (1)$$

$$\text{OML(\%)}=\left(1-\left[\frac{m_o(\theta)}{m_o(0)}\right]\right)100 \qquad (2)$$

$$\text{C-loss (\%)}=\left(1-\left[\frac{m_c(\theta)}{m_c(0)}\right]\right)100 \qquad (3)$$

$$\text{N-loss (\%)}=\left(1-\left[\frac{m_n(\theta)}{m_n(0)}\right]\right)100 \qquad (4)$$

Where $m_d(\theta)$, $m_o(\theta)$, $m_c(\theta)$, and $m_n(\theta)$ are the compost dry mass, organic mass, and total carbon mass, and total nitrogen mass (kg) at given time, respectively. $m_d(0)$, $m_o(0)$, $m_c(0)$, and $m_n(0)$ are the compost dry mass, organic mass, total carbon mass, and total nitrogen mass (kg) at the initial, respectively.

RESULTS AND DISCUSSIONS

Compost temperature

A typical temperature history during the composting are illustrated in Figure 3 for Q_{min} = 0.5 m^3/h and ξ = 0.4. Composting experiment lasted for 7.79 days. Composting reactors were turned manually on the 3.16th days of composting. The spikes in the temperature profiles indicates the manual mixing and also sampling times. After mixing, the temperature never reached to the previous level in all reactors. The close control of compost temperature at T_{sp} of 60°C with the small standard deviation was maintained by the aeration system.

O_2 and CO_2 concentrations

Figure 4 shows the change of the typical O_2 concentration as a function of time during composting when Q_{min} = 0.5 m^3/h and ξ = 0.4. The lowest oxygen concentrations for all reactors never dropped to 5%, which is the reasonable level for aerobic composting (Rynk, 1994).

Through the end of composting, all mixes showed an increase in oxygen level up to ambient level.

Organic matter was decomposed and transformed into CO_2 in all mixtures. Figure 4 presents the typical CO_2 concentration as a function of time.

Results showed that CO_2 histories reflected O_2 concentration histories.

Furthermore, the change of compost temperatures and O_2/CO_2 concentration became stable after the approximately 6.5th day of composting.

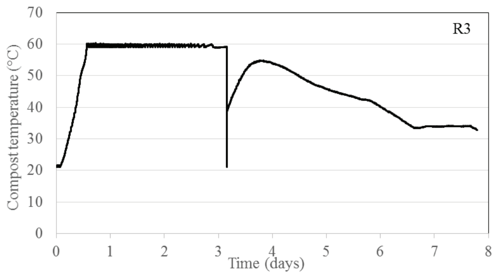

Figure 3. Typical compost temperature as a function of time when Q_{min}=0.5 m^3/h and ξ=0.4

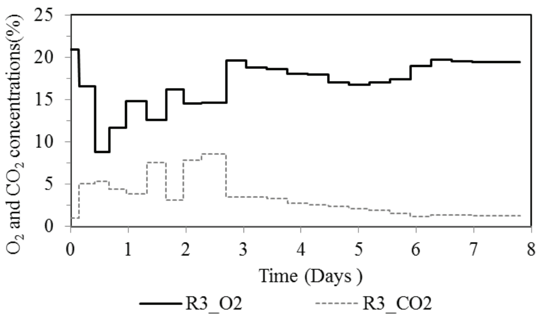

Figure 4. O_2 and CO_2 concentrations as a function time when Q_{min} = 0.5 m^3/h and ξ = 0.4

Compost moisture

Compost moistures as a function of time are listed in Table 3. Initial moisture for the mixture was set to 66% (wet basis), which is close to reasonable range (Rynk, 1992). The moisture content of compost in all the reactors decreased as the time progressed. The reduction in moisture content was parallel to temperature histories and faster at the thermophile stage (Keener et al., 2000). After manual turning, the temperature development for all rectors was weak and this reflected to the change in moisture of all reactors.

Table 3. The change of compost moisture as a function of time

Reactor	Composting duration (days)		
	0	3.16	7.79
R1	66.1±0.86	64.49±2.06	60.82±1.53
R2	66.1±0.86	60.34±2.61	61.37±0.85
R3	66.1±0.86	63.46±3.34	63.61±0.93
R4	66.1±0.86	60.72±0.90	60.54±0.00
R5	66.1±0.86	64.93±0.69	63.31±1.53
R6	66.1±0.86	59.26±1.84	62.21±0.35
R7	66.1±0.86	63.53±0.22	62.88±0.72
R8	66.1±0.86	63.50±2.05	62.84±1.08
R9	66.1±0.86	64.17±1.08	64.52±0.00
R10	66.1±0.86	60.81±2.41	60.18±0.40
R11	66.1±0.86	61.64±0.62	62.82±1.38
R12	66.1±0.86	64.09±3.18	60.96±2.87
R13	66.1±0.86	62.13±1.08	55.92±0.07
R14	66.1±0.86	61.27±0.33	57.01±2.43
R15	66.1±0.86	63.73±1.09	58.00±0.74

Organic matter

The change of organic matter as a function of time are listed in Table 4. Initial mixture contains sizeable organic content (>76%) initially due to raw materials which have high organic matter content. The organic matter of compost mix in all reactors decreased during the biodegradation process. Furthermore, studies showed that the highest organic matter degradation occurred during the thermophilic stage due to microbial activity (Ekinci et al., 2004).

The highest reduction in organic matter occurred when Q_{min} = 1.5 m^3/h with ξ = 0.2, 0.3 and 0.4 for R7, R8 and R9, respectively.

The resultant organic matter for R7, R8 and R9 were 67.08%, 66.15 and 68.22, respectively.

Table 4. The change of compost organic matter as a function of time.

Reactor	Composting duration (days)		
	0	3.16	7.79
R1	76.00±0.81	71.72±0.16	70.76±0.38
R2	76.00±0.81	73.03±0.31	71.41±0.40
R3	76.00±0.81	73.55±0.45	72.48±0.50
R4	76.00±0.81	70.61±0.53	69.84±0.18
R5	76.00±0.81	72.48±0.40	71.24±0.51
R6	76.00±0.81	71.80±1.49	71.30±0.42
R7	76.00±0.81	70.01±0.43	67.08±0.08
R8	76.00±0.81	68.86±1.16	66.15±0.20
R9	76.00±0.81	71.64±0.30	68.22±1.35
R10	76.00±0.81	71.35±0.13	69.94±0.43
R11	76.00±0.81	71.31±0.21	70.63±0.02
R12	76.00±0.81	72.81±0.25	70.10±0.33
R13	76.00±0.81	71.77±0.26	70.10±0.15
R14	76.00±0.81	71.30±0.03	69.54±0.85
R15	76.00±0.81	72.16±0.27	70.90±0.57

C/N ratio

C/N ratio was measured at the initial and final stage of composting. The change of C, N, and C/N ratio of reactors are listed in Table 5. All aeration rates led to decrease in C/N ratios. The magnitude of the reduction depends on decrease in organic matter in the reactors. The highest reduction existed at the rate of Q_{min} = 1.5 m^3/h with ξ = 0.2, 0.3 and 0.4 for R7, R8 and R9, respectively.

Composting losses as function of Q_{min} and ξ

The change of DML, OML, C-loss and N-loss with time as a function of time is presented in Table 6. DML and OML are an indicator of the overall composting success. Furthermore, the degradation of the organic matter during composting can be estimated by DML (Ekinci et al., 2002). Gaussian curve was applied to experimentally determined DML at different Q_{min} and ξ. DML as functions of Q_{min} and $\xi$was correlated and the resultant equation with R^2=0.81 (Eq.5) showed that the highest DML (25.77%) occurred when Q_{min} = 1.49 and ξ = 0.3. DML as functions of Q_{min} and ξ (Figure 5).

$$\mathrm{DML} = 25.77e^{-0.5\left[\left[\frac{Q_{min}-1.49}{1.27}\right]^2+\left[\frac{\xi-0.30}{0.26}\right]^2\right]} \quad (5)$$

Table 5. The change of C, N, and C/N ratio of reactors

Reactors	C (%)		N (%)		C/N ratio	
	0 (days)	7.79 (days)	0 (days)	7.79 (days)	0 (days)	7.79(days)
R1	38.04±0.24	30.53±0.66	1.52±0.02	1.34±0.04	25.11±0.51	22.88±1.10
R2	38.04±0.24	29.87±1.20	1.52±0.02	1.29±0.00	25.11±0.51	23.16±0.93
R3	38.04±0.24	28.30±0.97	1.52±0.02	1.22±0.01	25.11±0.51	23.19±0.53
R4	38.04±0.24	29.08±0.55	1.52±0.02	1.24±0.01	25.11±0.51	23.46±0.71
R5	38.04±0.24	27.80±0.62	1.52±0.02	1.17±0.01	25.11±0.51	23.75±0.24
R6	38.04±0.24	28.30±0.33	1.52±0.02	1.20±0.01	25.11±0.51	23.68±0.14

R7	38.04±0.24	28.81±0.39	1.52±0.02	1.25±0.04	25.11±0.51	23.05±0.47
R8	38.04±0.24	26.28±1.22	1.52±0.02	1.22±0.08	25.11±0.51	21.64±0.38
R9	38.04±0.24	27.57±0.35	1.52±0.02	1.22±0.06	25.11±0.51	22.63±1.33
R10	38.04±0.24	27.64±1.46	1.52±0.02	1.19±0.06	25.11±0.51	23.22±0.13
R11	38.04±0.24	27.66±0.75	1.52±0.02	1.12±0.00	25.11±0.51	24.70±0.67
R12	38.04±0.24	28.25±1.40	1.52±0.02	1.17±0.07	25.11±0.51	24.15±0.26
R13	38.04±0.24	31.28±0.36	1.52±0.02	1.30±0.02	25.11±0.51	24.10±0.04
R14	38.04±0.24	30.18±1.05	1.52±0.02	1.23±0.04	25.11±0.51	24.54±0.00
R15	38.04±0.24	30.55±0.76	1.52±0.02	1.25±0.01	25.11±0.51	24.43±0.33

Table 6. The change of DML, OML, C-loss and N-loss with time

Reactor	Q_{min} (m^3/h)	ξ	$m_d(0)$ (kg)	$m_d(\theta)$ (kg)	DML (%)	OML (%)	C-loss (%)	N-loss (%)
R1	0.5	0.2	13.54	11.37	16.01	21.81	32.63	25.95
R2	0.5	0.3	13.43	10.87	19.05	23.93	36.40	31.07
R3	0.5	0.4	13.66	10.89	20.26	23.96	40.72	35.80
R4	1.00	0.2	13.32	10.25	23.08	29.31	41.20	37.04
R5	1.00	0.3	13.62	10.41	23.60	28.39	44.15	40.98
R6	1.00	0.5	13.56	10.95	19.22	24.21	39.92	36.28
R7	1.50	0.2	14.05	10.69	23.92	32.85	42.40	37.25
R8	1.50	0.3	13.77	10.29	25.26	34.94	48.40	40.11
R9	1.50	0.5	13.76	10.16	26.12	33.67	46.46	40.51
R10	2.00	0.2	13.46	10.43	22.48	28.65	43.70	39.12
R11	2.00	0.3	13.40	10.11	24.54	29.87	45.16	44.21
R12	2.00	0.5	13.58	10.75	20.88	27.00	41.35	39.03
R13	2.50	0.2	13.57	11.20	17.49	23.89	32.16	29.31
R14	2.50	0.3	13.34	10.83	18.79	25.66	35.64	34.13
R15	2.50	0.5	13.59	11.29	16.89	22.47	33.25	31.42

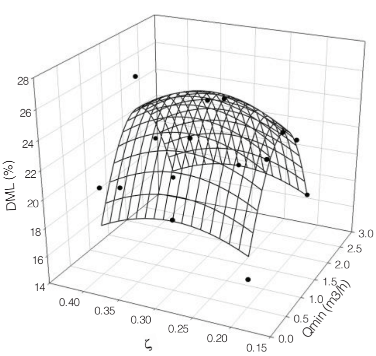

Figure 5. The change of DML as functions of Q_{min} and ξ

As for OML, regression analysis using Gaussian curve with R^2=0.81 (Eq.6) resulted in the highest OML of 33.22% when Q_{min} = 1.54 and ξ = 0.28. DML as functions of Q_{min} and ξ is given in Figure 6.

$$OML = 33.22e^{-0.5\left[\left[\frac{Q_{min}-1.54}{1.26}\right]^2+\left[\frac{\xi-0.28}{0.28}\right]^2\right]} \quad (6)$$

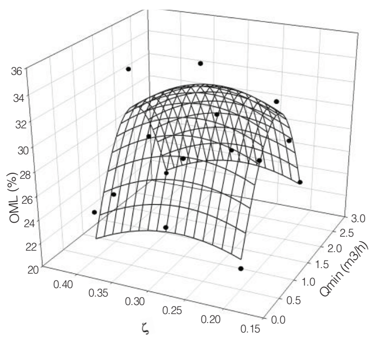

Figure 6. The change of OML as functions of Q_{min} and ξ

Larney et al. (2006) reported that composting leads to higher C and N-losses compared to stockpiling or a direct application to soil. Hao et al. (2004) added that the major concern of manure composting is to control C and N-losses since they reduce the agronomic value of compost and contribute to greenhouse gas emissions. Bicudo et al. (2002) states that nitrogen loss is an important consideration during composting from both a nutrient conservation standpoint and since atmospheric ammonia and nitrous oxides have been linked to a variety of adverse environmental and health effects. Manipulation of C/N ratios in composting reduces nitrogen volatilization substantially during manure composting (Ekinci et al., 2002). Gaussian curve was applied to experimentally determined C-loss at different $Q_{min}$and ξ. C-loss as functions of Q_{min} and ξwas correlated and the resultant equation with R^2=0.81 (Eq.7) showed that the highest C-loss (48.45%) occurred when Q_{min} = 1.46and ξ = 0.37. C-loss as functions of Q_{min} and ξ is given in Figure 7.

$$C-loss = 48.45e^{-0.5\left[\left[\frac{Q_{min}-1.46}{1.38}\right]^2+\left[\frac{\xi-0.37}{0.37}\right]^2\right]} \quad (7)$$

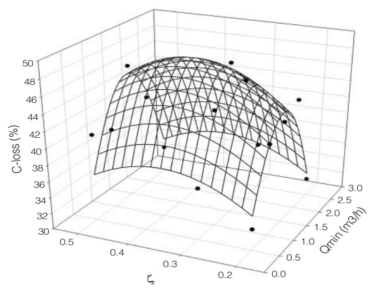

Figure 7. The change of C-loss as functions of Q_{min} and ξ

As for N-loss, regression analysis using Gaussian curve with R^2 = 0.79 (Eq.8) resulted in the highest N-loss of 44.29% when Q_{min} = 1.55 and ξ = 0.38. N-loss as functions of Q_{min} and ξ is given in Figure 8.

$$N-loss = 44.29e^{-0.5\left[\left[\frac{Q_{min}-1.55}{1.40}\right]^2+\left[\frac{\xi-0.38}{0.33}\right]^2\right]} \quad (8)$$

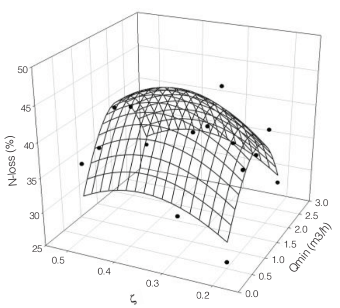

Figure 8. The change of N-loss as functions of Q_{min} and ξ

CONCLUSIONS

Composting of opium poppy processing solid wastes with poultry manure and rough sawdust was carried out using laboratory type composting reactors to determine the effects of the effects of aeration on composting loss (dry matter loss, organic matter loss, carbon loss, and nitrogen loss). Results showed that the highest losses occurred at the aeration rate of Q_{min} = 1.5 m^3/h. Losses as functions of aeration rate with on/off time showed that the highest losses existed at the aeration rate of Q_{min} = 1.5 m^3/h with on/off time (min) of 7.5/25-10.0/25.

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