



CO₂ Emissions in Aerobic Wastewater Treatment Process of Potato Processing Industry

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ABSTRACT:

This paper is about CO₂ emissions (CO₂e) in Aerobic biological treatment process for wastewater in potato processing industry which include direct emissions (Scope 1-biogenic activity in aerobic biological treatment process) after primary clarifier and indirect emissions (Scope 2-purchased electricity) used by surface aerators, motors and sludge dewatering equipment and electricity consumption in laboratory of effluent treatment plant (ETP) including the ETP office. The study of scope 3 includes use of chemicals in primary and secondary (aerobic) wastewater treatment process in ETP and waste transportation only. This study indicates that CO₂e under scope 1 and 2 both can be minimized by reducing the organic load and total nitrogen (TN) load. The organic load is considered in terms of BOD load in kg. This study indicates that CO₂e under scope 1, 2, and 3 increase as the organic load and total nitrogen increase and vice versa. CO₂e was found in the lower side for the period of Jan to April and increased from April onwards. The CO₂e due to N₂O emission is found in range of 2.8% to 3.4% of total CO₂e (scope1, 2 and 3) and 11% to 14% of Scope 1 emission which found in increasing order as the TN increased in wastewater. CO₂e through BOD removal of wastewater (scope 1) was found in range of 22% to 28% of CO₂e. The electricity consumption under scope 2 increased as the organic load increased. CO₂e due to electricity consumption was found in range 67.7% to 73.5% of Total CO₂e. The CO₂e due to electricity consumption is higher in scope 2 as compared to the CO₂e in aerobic Biotreatment in scope 1 and chemical consumptions and sludge transportation under scope 3.

I. INTRODUCTION

Temperature increase of earth surface is big global challenge, known as global warming. Some gases exist in the troposphere of the atmosphere like Carbon dioxide (CO₂), Methane (CH₄) Ozone (O₃) and Nitrous oxide (N₂O) are known as greenhouse gases (GHGs). The sunlight which reaches to the earth's surface, passes through these gases, some of the energy of sunlight get back to the space while some of the energy of sunlight is get trapped by these gases and remain on earth's atmosphere and contribute to increase the temperature of Earth's atmosphere. The phenomenon of temperature increase of earth surface is known as greenhouse effect. The phenomenon of the greenhouse effect is very important for the survival of humans, flora and fauna on the earth because this effect keep earth warm as required. If the greenhouse effect gets stronger then Earth surface becomes warmer than normal and a little increase in temperature causes

problems to humans, flora and fauna [1]. In other words, the thermal radiation of the sun falls on the earth surface and is reradiated in all the directions. Some reradiation from the surfaces of the earth surface sent back to the space and some reradiation occupied through above mentioned GHGs and exists in troposphere which causes rise in earth surface temperature than usual temperature. The six foremost GHGs, N₂O, CH₄, CO₂, hydrofluorocarbons (HFCs), sulfur hexafluoride (SF₆) and perfluorocarbons (PFCs), were specified in the Kyoto Protocol which causes adverse impact to the environment by elevation in temperature of earth surface than its average temperature [2]. The Global warming potential (GWP) is expression which define the involvement and contribution of GHGs which facilitate the assessment of global warming effect of GHGs with reference of classical gas CO₂.

Global warming potential on basis of hundred years for CO₂, CH₄ and NO₂ are 1, 25 and 298, respectively. So the emission of GHG having small quantity with high Global



warming potential has superior impact as compared to the GHG emission with lower GWP. For instance, Emission of nitrous oxide having quantity of 1 kilogram drive the equivalent temperature locking potential for 296 kilogram of carbon dioxide. [3, 4]. The description of Carbon dioxide equivalent (CO₂eq) is a measure, for the specified mixture and quantity of GHG. the amount of CO₂eq that would have the same GWP, when quantified over a specified timespan usually, hundred years [5, 6,7].

Type of Emissions- The CO₂ emissions (CO₂e) are classified under three terminologies namely scope 1, scope 2, and scope 3 though, this classification does not relate to the carbon foot print (CFP) of the product, which describes the total GHGs emissions produced during manufacturing of the product or a service over the diverse stages of their life cycle [8]. With reference to the GHG Protocol, the key clue behind this classification is to help demarcation of emission sources known as direct and indirect, establishing the clarity, transparency, and provide usefulness for different kinds of organizations and different rules, guidelines and strategies and CO₂ emission goals. These three scopes are outlined for GHG accounting and reporting commitments [9] while also making sure that different companies shall not report for emissions in the same scope. Scope 1 – Direct emissions: Emissions under Scope 1 include direct emissions from a source which controlled by the company [10,11]. This includes use of energy on the site, refrigerants, fuels, natural gas, and emissions from combustion in owned or supervised boilers and furnaces and release of CO₂eq in form of fumes, leaks of cooling liquid, methane, chemicals and emissions in wastewater treatment plant at manufacturing site [12,13]. Under scope 1, those direct emissions are accounted which regulated and managed directly by the reporting company. [14]. Scope 2- Indirect emissions: Under scope 2, those indirect emissions are accounted which are purchased or acquired energy [11,12]. The example of source of indirect emissions under scope 2 are heat, steam electricity, or cooling, that is produced off-site and consumed at the site or location of the reporting company. For example, purchase electricity from a utility company which generate electricity offsite, so these are considered under scope 2 indirect emissions [14]. However, if the reporting company or industrial facility produces its own energy on-site from owned or controlled sources, then accompanying emissions with the generation of energy are classified as direct emissions or scope 1

emissions [9]. Scope 3 – Indirect value chain emissions: The emissions in the value chain of the reporting company is regularized under indirect emissions known as Scope 3 emissions. GHG Protocol provided the boundaries under scope 3 emissions, which are of two types namely upstream and downstream emissions. Upstream emissions: The indirect GHG emissions within the company's value chain related to acquired or purchased goods and services which are generated from cradle to gate. [9] The eight numbers of upstream emission categories defined by the Greenhouse protocol are purchased goods and services, capital goods, fuel and energy related activities, upstream transportation and distribution, waste generated in operations, business travel, employee commuting and upstream leased assets. Downstream emissions: The indirect GHG emissions within the company's value chain related to sold goods and services and emitted after they exit the company's ownership or control. Downstream emissions result from the use are disposal of a business's products and services. The seven numbers of upstream emission categories defined by the Greenhouse protocol are downstream transportation and distribution, processing of sold products, use of sold products, end of life treatment of sold products, downstream leased assets, franchises and Investments [15,16]. Scope 1 and Scope 2 emissions in wastewater treatment: The GHG emissions are one of the major concerns in wastewater treatment plant [17] and it is ranked in top ten amongst the static sources of microbial (biogenic) CO₂e [16]. In this changing climate and concerns of environmental impact draw the attention and great interest about evaluation of GHG emissions from wastewater treatment plants. [18]. The various treatment methods are used in wastewater treatment processes like Biological (secondary treatment- Aerobic and Anaerobic), Primary treatment (Coagulation, flocculation and clarification), Tertiary treatment (Chemical treatment including advanced oxidation processes) and produces three primary GHGs; carbon dioxide (CO₂), nitrous oxide (N₂O) and Methane (CH₄) This study is focused on CO₂e emissions in aerobic biological treatment process [19]. Wastewater treatment and sludge treatment and digestion produce on-site GHG emission are under scope 1 emissions. The electricity consumption in aerobic wastewater treatment, required by surface aerators in this study are considered under Scope 2 emissions. The remaining indirect emissions, referred to as scope 3 emissions, are related to the production and



transportation of chemicals outside of the plant [20]. The CO₂ emissions which produce off-site by wastewater treatment plant include transportation, using chemicals and outside sewage sludge treatment and disposal [21,22]. This article takes an aerobic biological wastewater treatment plant of a potato processing industry to analyze the Direct and Indirect CO₂ emissions under scope 1 and 2 in Aerobic Wastewater treatment process. Indirect GHG emissions (Scope-2) based on the electricity consumption in wastewater treatment process and direct emission (Scope-1) include the biogenic CO₂e during Aerobic Biological treatment process of wastewater only. The chemical consumption used in treatment process and sludge waste transportation (Scope-3) are covered.

II. METHODOLOGY

- A. Sample Collection: The composite sample taken after primary clarifier. The wastewater generated from entire manufacturing process like peeling, cutting, blanching, cleaning in place (CIP) of Machineries, cleaning, washing, Cooling tower and Boiler blow down. The composite sample was taken on daily basis.
- B. Method of Sample Analysis: APHA “Standard Methods for the Examination of water and wastewater, 23rd Edition-2017 were used to analyze the sample as per following method.
1. BOD: IS 3025 (Part 44): 1993 (RA 2014)
 2. Ammonical Nitrogen: APHA, 23rd Edition 2017 - 4500-NH₃-B, C
 3. Total Nitrogen: Method 4500 N-C
 4. CO₂ emission calculation method: CO₂ emission calculation done by taking the emission factors given by Intergovernmental Panel on Climate change (IPCC) and relevant research articles as cited in this article. The month wise values of the parameters are an average daily.

GHG calculations in Aerobic treatment of wastewater (Direct emissions under Scope 1):

There are three processes in aerobic biological treatment of wastewater, namely

1. BOD oxidation
2. Endogenous decay
3. Nitrogen removal:



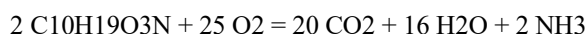
The N to CO₂ ratio is $6 * 14 : 5 * 44$, which equals $1 : 2.62$. However, it should not include in the calculation because the denitrifies use BOD as a carbon source, the calculation of the CO₂ produced is already included in the calculation for BOD oxidation but CO₂ e due to N₂O emissions calculated separately. The GHG emission from aerobic biological treatment of wastewater comprised of three stages, the BOD oxidation, removal of the nitrogen by nitrification and denitrification process and endogenous respiration. Equation (1) used to quantify the greenhouse gas emission during BOD oxidation. Equation (2) used to quantify the greenhouse gas emission during endogenous respiration.

CO₂ emissions in BOD Oxidation:

$$\text{CO}_2\text{BOD}_{\text{ox}} = 1.1 * \frac{\text{BOD}_{\text{ox}}}{f_{\text{BOD}}} - 1.42 * X_{\text{net produced}} \quad [23].$$

CO₂BOD_{ox} is the generation of CO₂ on stage of BOD oxidation (kg), 1.1 is the defined ratio of CO₂ generation and O₂ consumption,

The conversion factor for CO₂ from BOD_{ox} is 1.1 which derived from the given chemical reaction of elemental composition of BOD which is C₁₀H₁₉O₃N



We find here ratio of O₂ and CO₂ through this calculation based on the elemental reaction. $25 * 32 : 20 * 44$ which is $1 : 1.1$. So 1 kg of O₂ produces 1.1 kg of CO₂. BOD_{ox} is bio-oxidized BOD (kg), and f_{BOD} is the ratio of BOD₅ and BOD_u (0.68) [24], this value is considered for BOD₃ instead of BOD₅. $X_{\text{net, produced}}$ is net sludge production per day(kg/day), 1.42 = oxygen demand of biomass (g/g) [23].

$X_{\text{net, produced}} = Y_{\text{obs}} * \text{BOD oxidized}$
 $X_{\text{net produced}}$ in the treatment process is the net biomass produced per day (kg VSS/day). The observed biomass yield calculated by the given equation $Y_{\text{obs}} = Y / (1 + k_d * \text{SRT})$ Y_{obs} is the observed biomass yield which is measured in kg VSS/kg BOD oxidized, Y is yield measured in kg VSS/kg BOD oxidized, the value of Y_{obs} is considered as 0.24, SRT is considered in days which is sludge retention time.

The oxidized BOD is calculated through the equation given below:



BOD_{ox} in aeration tank in kgBOD = Q influent (m³/day) * (BOD_{3in} mg/l)/1000 – Q effluent (m³/day) * (BOD_{3out} mg/l)/1000

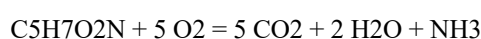
The soluble BOD remaining in the effluent generates CO₂ emissions when organic matter is disposed to land, river or sea [23]. This part was not calculated as the aerobic treated wastewater was recycled through post treatment by membrane technology.

CO₂ decay in Endogenous respiration:

$$\text{CO}_2\text{decayed} = 1.947 * Q \text{ influent} * \text{HRT} * \text{MLVSS} * kd$$

CO_{2,decayed} is CO_{2e} produced in process of endogenous respiration (kg), 1.947 is the factor used for CO₂ production(kg) for the decay of 1 kg biomass, The factor 1.947 is derived from the elemental composition of biomass given below. Q_{in} is the wastewater influent flow in aeration tank in (m³ /d), HRT denotes the hydraulic retention time of wastewater in aeration tank, mixed liquor volatile suspended solids is denoted as MLVSS in (kg/m³) in aeration tank, kd is the endogenous decay coefficient (0.05 1/d) [25].

C₅H₇O₂N is the elemental composition of biomass which derived the factor 1.947



We find the biomass to CO₂ ratio with help of above stoichiometric equation of elemental composition 113: 5*44 which equals 1: 1.947. This show that decay of one kg of biomass produce 1.947 kg of CO₂. [23].

CO₂ emissions due to N₂O emissions: The ammonical nitrogen NH₄-N and total nitrogen TN is removed more than 90% and 65% respectively during the process of aerobic biological treatment so it is not justified to include only the nitrous oxide (N₂O) emission in the wastewater treatment process as suggested by IPCC [26]. The N₂O emissions control mostly includes maintaining the appropriate dissolved oxygen (DO) concentration in aerobic biological treatment system and prevention of the NO₂-N accumulation and by providing the sufficient carbon source in treatment process during denitrification [23]. The CO₂ emission in nitrification process affects slightly because of lower emission factor (EF) of 0.005 kg N₂O-N/kg N denitrified. Maximum of the N₂O releases in

nitrification process during the process of biological nutrient removal [27]. Another N₂O emission factor (EF) in denitrification process is reported as 0.035 kg N₂O-N/kg N denitrified [28]. Proper oxygen managed aerobic treatment process and increasing aeration rate, increases the oxidation rates of NH₄-N and NO₂-N, and decreases the N₂O emission rate. The bacterial activity for ammonia oxidation governed by the sufficient oxygen supply and this oxidation activity increases with increase in aeration rate and resulting N₂O EF decreased [29]. The EF of N₂O is reported in the range of 5.1%–6.6% [30]. The NO₂-N concentration reported above 220 mg/l, shown very little effect on N₂O emission [31]. The reviewed and revised EF of N₂O reported 0.016 kgN₂O-N/ kg TN_{in}fluent which is 1.6% of wastewater influent have mass load of total nitrogen, The recent default EF of N₂O is 1.6% of influent nitrogen in wastewater, proposed by IPCC 2023. It is reported in several studies that there are wide dissimilarities in N₂O EF while working in lab scale and full-scale operation of wastewater. EF in range of 0% to 25% in different studies have reported also. This dissimilarity can be accredited to the different process arrangement and dynamic conditions in each case. EF were found in range of 0.01% to 1.8% with respect to the wastewater influent TKN. Seven wastewater treatment plants of numerous configurations investigated and then concluded N₂O EF in range of 0.6–25.3% with respect to the denitrified nitrogen. N₂O emission can be calculated by following formula.

$$\text{N}_2\text{O emission} = Q \text{ influent} (\text{TN in} - \text{TN out}) * R_{\text{N}_2\text{O}}$$

Where R_{NO₂} is EF of N₂O which is 0.016 kgN₂O-N/ kg TN_{in}fluent.

$$\text{CO}_2 \text{ emission due N}_2\text{O Emission} = \text{N}_2\text{O Emission} * 296$$

Total CO₂ emissions in process of Aerobic biological treatment of wastewater in kgCO₂/day is:

$$\text{CO}_2, \text{biotreatment} = \text{CO}_2, \text{decay} + \text{CO}_2, \text{BOD}_{\text{ox}} + \text{CO}_2, \text{emission due to N}_2\text{O emissions}$$

CO₂ emission in Aerobic biological treatment by Electricity Consumption (Indirect emissions- Scope 2):

The indirect CO_{2e} emissions under scope 2 in aerobic biological treatment of wastewater is caused by electricity consumption [20]. Electricity consumption is one of the major CO₂ emitters in Wastewater treatment plant [23]. All



the electricity consuming units in wastewater treatment plant like instruments and equipment of wastewater laboratory, wastewater pumping system, sludge dewatering system at treatment site, electrically operated motors of surface aerators, power consumption in office of wastewater treatment plant are covered in estimation of power consumption which recorded in energy meter in kwh monthly parallel to the monthly operational parameters. The power consumption mentioned in table 2. The EF for electricity consumption kgCO₂/kWh CO₂ emissions considered 0.82 in CO₂ baseline data for the Indian Power Sector.

CO₂ emissions calculations in chemical Consumption and sludge transport (Indirect emissions under Scope 3): Three chemicals were in use in wastewater treatment plants coagulant and flocculant for solid settling and sludge dewatering and last one is ferric chloride which was used for phosphorus removal in aerobic wastewater treatment.

CO₂ emissions calculation in chemical Consumption (Polymers-coagulant and flocculant and Ferric chloride) in aerobic wastewater treatment and in sludge transportation studied by using the following equations:

$$\text{CO}_2\text{chemical} = W_{\text{chemical}} * F_{\text{chemical}} \quad [23].$$

CO₂ chemical is the CO₂ emission due to chemical usage in treatment process, W chemical is the quantity of chemical used in treatment process (kg), F_{chemical} is the factor of CO₂ emission, which is considered (1.182).

Values of EF for polymer use are very different in the literature: 4.25 kg CO₂e/kg polymer, 2.62 kg CO₂e/kg of active substance or 1.18 kg CO₂e/kg of active substance. EF for polymer 1.18 kg CO₂e/kg and for ferric chloride 0.33 kg CO₂e/kg FeCl₃ considered in this study.
CO₂transport = L * f_{fuel} * f_{transport} [23].

CO₂ emission in sludge Transportation: CO₂ emission factor given by the Environmental Protection Agency (EPA) and he endorsed the value 1.387 kg CO₂ per mile movement of truckload, which is around equal to the emissions reference from a model year 2021 truck. It is reported that approximately 32% of the trucks moving on the road have their emission factor rate at or above 1.760 kg CO₂ per mile, and approximately 10% have an emissions factor rate at or above 1.857 kg CO₂ per mile which are 25-34% higher emission rate than the endorsed rate of CO₂ emission.

(<https://supplychainmanagement.utk.edu/blog/measuring-scope-3-truck-emissions>).

1.387 kg CO₂ per mile is considered in this study. CO₂transport is the CO₂ emission during the sludge transportation activity outside the reporting company(kg), L is the total distance (up and down) of the plant to the composting site or secured landfill site(km), f_{fuel} is the known fuel efficiency of used vehicle during the sludge transportation 0.554 L/km. The factor of f_{transport} is 2.5 kg CO₂/L for petrol. .

Table 1A & 1B: Wastewater characteristics after Primary Clarifier & secondary (Aerobic biological) treatment

Table 1 A : Influent Parameters to Aeration Tank after Primary Clarifier										
Year 2023	Flow m ³ /day	BOD ₃ mg/l	Kg BOD ₃	MLVSS mg/l	Kg/m ³ MLVSS	NH ₄ -N mg/l	TKN-mg/l	NH ₄ -N-kg	Total TKN-kg	HRT days
Jan	880	1230	1082	2231	1.96	32.00	68	28.16	60	2.13
Feb	922	1254	1156	2240	2.07	32.62	62	30.08	57	1.90
Mar	945	1342	1268	2312	2.18	32.83	70	31.02	66	2.13
Apr	962	1368	1316	2264	2.18	34.36	64	33.05	62	1.86
May	978	1434	1402	2328	2.28	35.42	71	34.64	69	2.00
Jun	986	1446	1426	2341	2.31	39.26	65	38.71	64	1.66
Jul	992	1461	1449	2276	2.26	35.24	70	34.96	69	1.99
Aug	981	1563	1533	2354	2.31	37.68	73	36.96	72	1.94
Sep	980	1621	1589	2408	2.36	39.62	82	38.83	80	2.07
Oct	984	1768	1740	2462	2.42	40.14	81	39.50	80	2.02
Nov	914	2112	1930	2390	2.18	42.26	86	38.63	79	2.04



Dec	800	2164	1731	2317	1.85	42.84	84	34.27	67	1.96
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Table 1 B : Treated Effluent Parameters after Secondary Clarifier

Year 2023	BOD3 mg/l	Kg BOD3	NH4-N mg/l	NH4-N, kg	Total TKN mg/l	Total NH4-N, kg	Total TKN -kg	BOD3 removed (kg)	TKN removed (kg)
Jan	18.2	16.02	1.82	1.60	2.1	1.60	1.85	1066.38	57.99
Feb	21.24	19.58	1.86	1.71	2.36	1.71	2.18	1136.60	54.99
Mar	21.93	20.72	1.91	1.80	2.32	1.80	2.19	1247.47	63.96
Apr	21.65	20.83	2.11	2.03	2.24	2.03	2.15	1295.19	59.41
May	21.88	21.40	2.22	2.17	2.31	2.17	2.26	1381.05	67.18
Jun	21.92	21.61	2.26	2.23	2.42	2.23	2.39	1404.14	61.70
Jul	23.42	23.23	2.14	2.12	2.15	2.12	2.13	1426.08	67.31
Aug	23.84	23.39	2.21	2.17	2.24	2.17	2.20	1509.92	69.42
Sep	23.26	22.79	2.36	2.31	2.3	2.31	2.25	1565.79	78.11
Oct	25.62	25.21	2.41	2.37	2.36	2.37	2.32	1714.50	77.38
Nov	26.24	23.98	2.72	2.49	2.53	2.49	2.31	1906.38	76.29
Dec	27.42	21.94	2.84	2.27	2.68	2.27	2.14	1709.26	65.06

Table 2A & 2B: CO2 emissions in Scope1, 2 and 3 and Total CO2 emissions

Year 2023	X net, produced = Y obs * BOD oxidized	CO2, BODox, Equation-1 (Scope-1)	CO2decayed Equation-2 (Scope-1)	N2O e Equation-3 (Scope-1)	CO2 e due to N2O emission (Scope-1)	Power consumption in kwh (Scope-2)	Coagulant, flocculant (kg) (Scope-3)
Jan	255.93	1361.61	357.4	0.93	274.65	7820	140
Feb	272.79	1451.27	352.33	0.88	260.42	7960	182
Mar	299.39	1592.82	428.56	1.02	302.9	8142	189
Apr	310.85	1653.76	379.92	0.95	281.38	8220	203
May	331.45	1763.39	434.52	1.07	318.16	8690	208
Jun	336.99	1792.88	366.82	0.99	292.23	8570	224
Jul	342.26	1820.89	433.11	1.08	318.77	8662	230
Aug	362.38	1927.93	427.26	1.11	328.75	8874	232
Sep	375.79	1999.27	465.95	1.25	369.91	9120	240
Oct	411.48	2189.16	468.3	1.24	366.48	9216	245
Nov	457.53	2434.16	395.54	1.22	361.32	9468	252
Dec	410.22	2182.47	283.06	1.04	308.11	9492	248



Table 2B: CO2 emissions in Scope1, 2 and 3 and Total CO2 emissions

Year 2023	Total BOD3 removed per day (kg)	Total Nitrogen removed (kg)	Scope 1/day-CO2eq %	Scope 2/day-CO2eq %	Scope 3/day-CO2eq %
Jan	1066.38	57.99	22.84	73.45	3.71
Feb	1136.60	54.99	23.02	72.78	4.20
Mar	1247.47	63.96	24.76	71.12	4.13
Apr	1295.19	59.41	24.45	71.20	4.34
May	1381.05	67.18	25.01	70.82	4.17
Jun	1404.14	61.70	24.72	70.84	4.45
Jul	1426.08	67.31	25.41	70.15	4.43
Aug	1509.92	69.42	25.76	69.83	4.41
Sep	1565.79	78.11	26.28	69.32	4.39
Oct	1714.50	77.38	27.31	68.25	4.44
Nov	1906.38	76.29	27.84	67.73	4.43
Dec	1709.26	65.06	25.11	70.46	4.43

Table 3: CO2e % contribution of Scope 1, 2 and 3

Year 2023	Ferric Chloride (kg) (Scope-3)	Sludge transportation site (Km) (Scope-3)	CO2 e due to Electricity (kg)	CO2 e due to use of coagulant and flocculant (kg)	CO2 e due to Ferric chloride (kg)	CO2e in transportation (kg)	Total CO2e (kg)
Jan	355	30	6412.40	165.20	117.15	41.61	8730.02
Feb	365	30	6527.20	214.76	120.45	41.61	8968.05
Mar	372	30	6676.44	223.02	122.76	41.61	9388.12
Apr	394	30	6740.40	239.54	130.02	41.61	9466.63
May	402	30	7125.80	245.44	132.66	41.61	10061.58
Jun	410	30	7027.40	264.32	135.30	41.61	9920.56
Jul	412	30	7102.84	271.40	135.96	41.61	10124.57
Aug	436	30	7276.68	273.76	143.88	41.61	10419.87
Sep	452	30	7478.40	283.20	149.16	41.61	10787.50
Oct	486	30	7557.12	289.10	160.38	41.61	11072.14
Nov	512	30	7763.76	297.36	168.96	41.61	11462.71
Dec	470	30	7783.44	292.64	155.10	41.61	11046.42

Note: Emissions from biogenic activity only studied in Aerobic biological treatment under scope 1 emissions, Electricity consumption under scope 2 and Chemical consumption and sludge transportation studied under scope 3 emissions.

III. RESULTS AND DISCUSSION

Scope1 and Scope 2 Emissions: Table 1 has the analysis report of BOD load, ammonical nitrogen load, total nitrogen load and their removal after biological (secondary

treatment) for the measured wastewater flow after primary clarifier. It shows the average value of each month from January to December. Based on the analysis report and organic loading in terms of kgBOD, Ammonical nitrogen and total nitrogen loading and their removal in table 1, the



CO₂ emission calculated and reported in table 2. The table 3 include the percentage contribution of each identified scope in this study. The CO₂e in Aerobic Biotreatment of wastewater as the organic load (BOD kg) increases in wastewater with time because organic load content increases with time in potatoes due to increase in sugar content. In the 1st quarter, January to March period the organic load found lower side in wastewater as compared to the 2nd, 3rd and 4th quarter. The CO₂e in Aerobic Biotreatment of wastewater depends on the wastewater characteristics mainly in terms of Organic load and Total Nitrogen load which Oxidizes in process. Higher load will have higher CO₂e and vice versa. Some researchers report, though N₂O has higher GWP, so consideration of this emission is not impactful in the calculation because the carbon source is utilized in form of BOD by denitrifying bacteria. Thus, it is not justified to add this amount in CO₂e. [23, 26, 27], because effective design of the Process and operation conditions and their control are crucial which influences the denitrification process, so these are deciding factor of the N₂O emissions. The CO₂ becomes oxidation, endogenous decay and CO₂e due to N₂O emissions are found near about in same ratio in average value of each month because the BOD and Total Nitrogen (TN) characteristics of wastewater changes parallel to the season and all values increased with time as potato become older. The CO₂e due to N₂O emission is found in range of 2.8% to 3.4% of total CO₂e (scope 1, 2 and 3) and 11% to 14% of Scope 1 emission which found in increasing order as the TN increased in wastewater. The CO₂e under biotreatment of wastewater (scope 1) was found in range of 22% to 28% of CO₂e. Accordingly, electricity consumption under scope 2, as the Oxygen demand increased due to the higher organic load then electricity consumption increased required for aerators to maintain the dissolved oxygen (DO), pumps, sludge dewatering system and other supporting equipment which consume the electricity. CO₂e due to electricity consumption was found in range 67.7% to 73.5% of Total CO₂e. The CO₂e due to electricity consumption is higher in scope 2 as compared to the CO₂e in Biotreatment in scope 1 is similar finding as reported [19]. in the order of CO₂e due to N₂O emissions > CO₂e due to BOD removal > CO₂e due to electricity consumption. The contributing component for CO₂e emission varies in reports of many researchers which is dependent on wastewater flow and characteristics of wastewater and selection of treatment technologies, same is

reported [19]. The GHG emission depend on the organic contents in wastewater. It is reported that direct CO₂e from wastewater treatment processes pays more than 60% of the carbon footprint in wastewater treatment plant and energy consumption pay over 30% involvement to the carbon footprint [20]. This percentage contribution reflects that researcher considered all the aspects of Scope 1 emissions and treatment technology used was anaerobic reactor while in this study, the CO₂e limited for biotreatment of wastewater only.

Scope 3 Emissions: Though Scope 3 has wide range which is comprised of downstream process emissions and upstream process emissions which have classified further under fifteen categories [8,14,15] and herein aerobic wastewater treatment instead of covering all the aspects of emissions under this scope, we studied the CO₂e due to use of coagulant, flocculant consumption used in sludge settling and sludge dewatering. CO₂e due to ferric chloride consumptions used for phosphorus removal in aerobic treatment of wastewater and CO₂e due to sludge transportation. The CO₂e of waste to landfill, composting and sludge digestion were not studied. The results presented in table 2 show that CO₂e is increasing order as the organic load in wastewater increased. The CO₂e of scope 3 was found in range of 3.71% to 4.45% of total CO₂e (scope 1, 2 and 3). The CO₂e due to chemical consumption and sludge transport under scope 3 is lower than the CO₂e of biogenic activity under scope 1 and electricity consumption under scope 2 which is like the report of Chai Chunyan [28]

IV. CONCLUSIONS

The results of the paper show CO₂ emission in the order as given herein CO₂e due to N₂O emissions > CO₂e due to BOD removal > CO₂e due to electricity consumption. CO₂e under Scope 2 is found to be higher than CO₂e under scope 1 and 3 because Scope 1 study covered aerobic biotreatment of wastewater only and scope 3 covered chemical uses and sludge transportation only. The CO₂e of waste to landfill, composting and sludge digestion were not studied.

It is found in this study that the most contributing component for CO₂e under scope 1, 2 and 3 varies in each month which was depended on wastewater flow and characteristics in terms of organic load and total nitrogen load. Results mentioned in table 2 and table 3 indicate that as the organic load and total nitrogen load increase the CO₂e under scope 1, 2 and 3 increase and vice versa. As the potatoes become older and stored, their metabolic



activity remains in continue and sugar and starch content increase and finally come into the wastewater during various steps of processing activities like peeling, deskinning, cutting and blanching. There is scope for reduction in scope 1 and scope 2 emissions in aerobic biogenic activity and electricity demand respectively by reducing the organic load and total nitrogen load in primary treatment of wastewater in existing treatment system. This can be further reduced by adopting the Biological Anaerobic treatment technologies to reduce the electricity consumption under scope 2 and reduction in sludge treatment, disposal and aerobic biogenic activity under scope1emissions. The replacement of aerobic treatment of wastewater by Anaerobic treatment of wastewater will save the power cost by reduction in electricity demand in treatment process and will produce the biogas also, which can be utilize as fuel in boiler and will promote to sustainable development and treatment cost advantages. In addition to this, use of renewable energy in process operations and control of wastewater treatment will help further to reduce CO2 emissions.

V. REFERENCES

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