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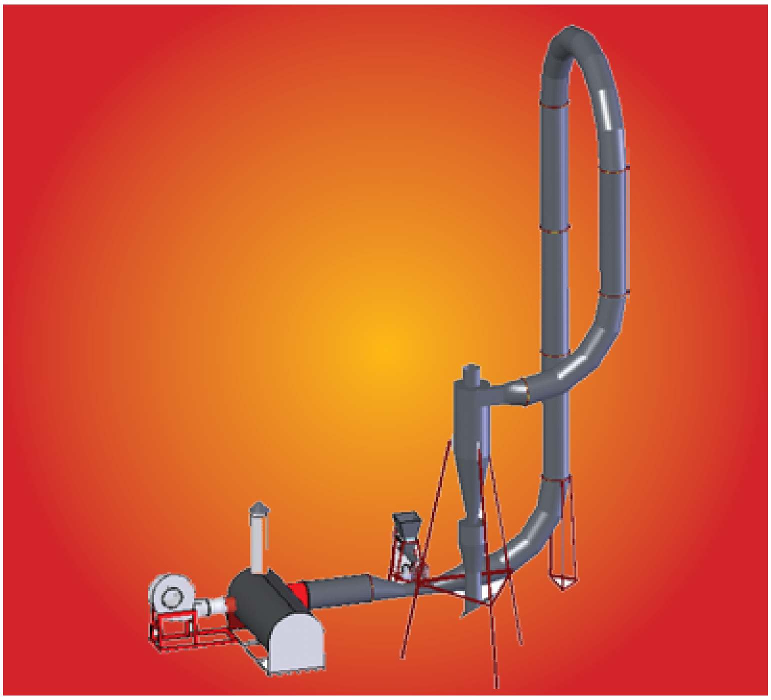

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Cover photos:
1. Flash dryer model
2. Dr Alfred Dixon, Dr Tarawali and other dignitaries at the commissioning ceremony of the IITA, RTEP, RMRDC, Godilogo sponsored flash dryer project
3. Professor Ayo Kuye (University of Port Harcourt) the team leader of the flash dryer design/fabrication team explaining the working principle of the flash dryer
4. High quality cassava flour produced
5. Motor control panel

Preface

The International Institute of Tropical Agriculture (IITA), in the bid to tackle the increased demand for a flash dryer for cassava flour in Nigeria assembled a team of engineers drawn from academia, research institutes, and the private sector, as well as fabricators who had worked on cassava flour dryers in the past.

Their task was as follows:

- Study the existing flash dryers in Nigeria
- Study the flash dryers from other regions
- Identify the gaps
- Develop an appropriate framework for the local fabrication of an efficient flash dryer for the production of cassava flour

These objectives tally with those of the Raw Materials Research and Development Council (RMRDC), Nigeria, which had earlier embarked on the promotion of the design and fabrication of various equipment for cassava processing.

To achieve these objectives, two workshops were organized by IITA. The first was held between 2 and 7 July 2006 and the second from 3 to 14 October 2006 with two fabricators from Brazil in attendance. The final output from these workshops was the setting up of a Design Team for the flash dryer.

The Flash Dryer Design Team was to design, fabricate, install, as well as test-run an efficient and cost-effective flash dryer. To achieve this, several meetings and study tours were done by the team sponsored by IITA, Root and Tuber Expansion Program (RTEP) and RMDRC. Godilogo Farms provided funds for the purchase of materials and also made available its workshop for the fabrication and final testing of the machine.

This publication is a product of these efforts. It has six sections which give the reader details about the technical aspects of design and fabrication. It is provides fabricators with the specifications for an efficient flash dryer and helps to fulfill the aspiration of cassava processors, equipment fabricators, the Government, and people of Nigeria and of Africa in general.

Engr. (Prof.) A.P. Onwualu
Director-General/CEO
Raw Materials Research and Development Council

Acknowledgments

The International Institute of Tropical Agriculture gratefully acknowledges the following investors in the Integrated Cassava Project for their cooperation and support: the Federal Government of Nigeria, the Niger Delta Development Commission, Shell Petroleum Development Company of Nigeria, the Nigerian National Petroleum Corporation, and its joint venture partners, the United States Agency for International Development, and the State Governments in Nigeria.

The alliance which is greatly appreciated between IITA and RMRDC, RTEP of IFAD, and a private company, Godilogo Farms, Obudu, Cross River State, has materialized into this publication. The assistance given by Mr Ayo Odebisi and his workers at Godilogo Farms during the fabrication is also appreciated.

Special thanks go to the various flash dryer fabricators (Peakproducts, Nijilukas, Octec, and others from Nigeria and the D'Andrea Company from Brazil) for sharing their experiences on flash dryers with the design team during the initial stage of the project. We are also indebted to the Director General of Federal Institute of Industrial Research, Oshodi; the Director, Scientific Equipment and Development Institute, Enugu; the Program Manager, Edo Agricultural Development Program ; Vice-Chancellors of the University of Port Harcourt, Rivers State, University of Ibadan, Oyo State, and University of Agriculture, Abeokuta, Ogun State, for releasing their staff to participate actively in the project.

Dr Gbassey Tarawali
Project Manager
Cassava Enterprise Development Project (CEDP)

Contents

Introduction

Cassava is a mainstay of over 200 million people in tropical Africa. It is a major food crop particularly in the developing countries of the sub-Saharan region (Hahn et al. 1989). It is produced under various agroecological conditions, some of which are quite unsuitable for many other crops. This makes it a reliable food security crop (Onabolu et al. 1998). Hence various governments in the developing countries have promoted the development of value-added products from this crop for human consumption, industrial uses, and export. The increased production and associated processing to improve market value are set to fight hunger and poverty (Onyeka et al. 2005).

Cassava which is mainly grown for its starchy tuberous roots as a valuable source of cheap calories for low income earners and resource-poor farmers has now gained a strategic position in the world trade. It is a crop that is also traded locally. There are numerous ways of processing and consuming cassava, depending on the locality. Two broad categories are consuming them as boiled roots and as processed products after processing into dry granules and flours which may or may not be fermented.

As a result of urbanization and changing eating habits, the consumption of leavened wheat bread has increased in Nigeria. However, because of the prevailing climatic conditions, Nigeria cannot produce enough wheat to satisfy the demand and must rely on imports which are bought with scarce foreign currency. By 1995, the value of wheat and wheat flour imports in Nigeria exceeded US$293 million (FAO and IFAD 2004). To reduce the import bill on wheat, the Federal Government of Nigeria institutionalized a policy in 2004 which compelled flour mills to include 10% cassava flour in all flour produced in Nigeria. The implementation of this policy required 200,000 t of cassava flour out of which only about 10,000 t can be supplied.

Drying is one of the unit operations in the processing of cassava roots into flour. The selection of an appropriate drying method is necessary to ensure good quality products and prolong their shelf life. Flash dryers have been reported to be one of the most economical choices for drying mash and solids that have between 30 and 40% moisture content.

The name “flash” dryer originates from the fact that drying is carried out in a short span of time, usually 0.5 to 3 seconds. The principle of flash drying is to evaporate surface moisture instantaneously. Wet particulate material is entrained in hot gas or steam flowing through an insulated duct. The particles are dried and the gas or steam temperature decreases (Saastamoinen 1992). In most systems, air is used as the gas. It is a well-known fact that the surface area of a wet lump increases as the size of the lump decreases. The wet cake is disintegrated into fines to increase the surface area. The drying is instantaneous and the material remains at the wet bulb temperature of air, hence it is also called “wet bulb drying”. The air velocities are similar to that of pneumatic conveying; the powder remains suspended in air and is conveyed while drying. It is therefore sometimes called a pneumatic dryer.

The schematic diagram of a typical flash dryer is shown in Figure 1. The process is as follows.

- Feedstock is introduced through a feed mechanism.
- The air after passing through an air filter is heated in a hot air generator or steam/thermal fluid based radiator. The feedstock is dispersed into the hot-air stream and gets thoroughly mixed.
- The pulverized material mixed with hot air is conveyed through the drying duct to the cyclone by the pressure created by the blower or an aspirator.
- The time taken by the material to travel through the drying duct is called the residence time of drying.

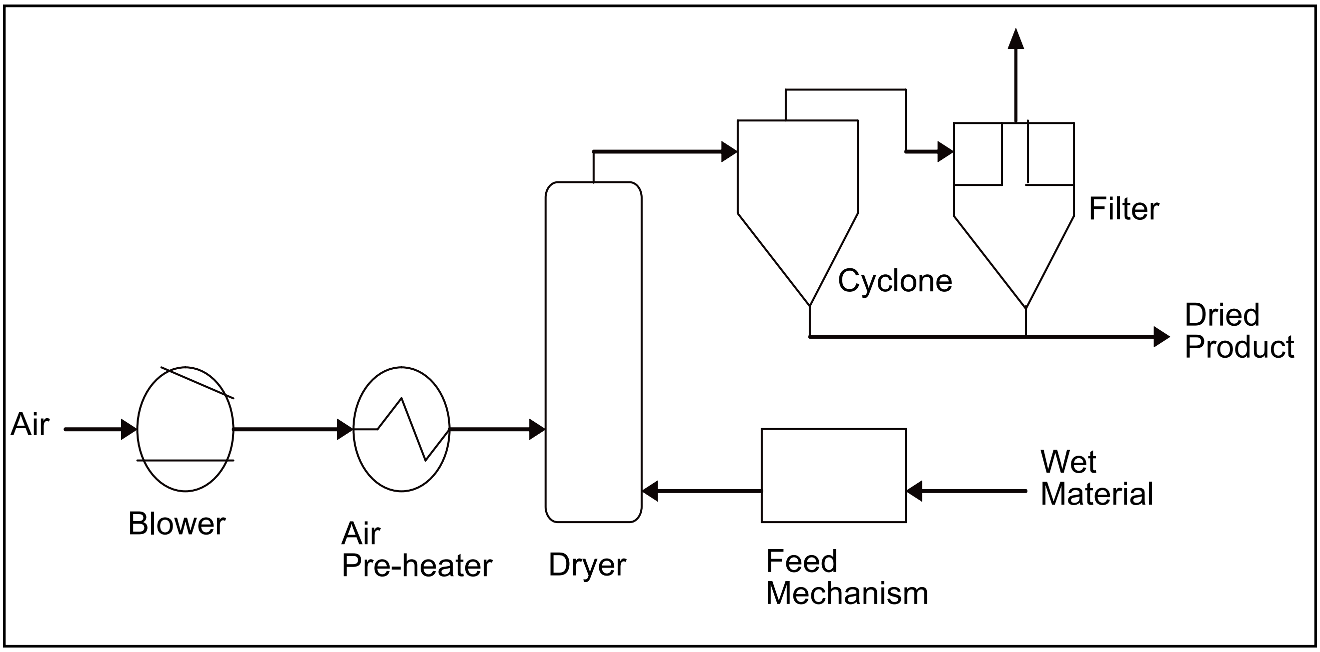

Figure 1. Schematic diagram of a typical flash dryer.

- The material loses moisture and this is absorbed by the hot air. The temperature of air is reduced while its humidity increases.
- Separation of dried product and air takes place in the cyclone. Powder is discharged from the cyclone through powder discharge valves.
- Fine particles that escaped from the cyclone are trapped by a bag filter.
- The air coming out of bag filter is dust free and conforms with pollution control norms.

The major constraints in cassava processing include the low capacity of processing equipment and poor engineering infrastructure for the development of processing equipment.

This publication presents the design of a flash dryer that can be used to dry cassava cake to produce high quality cassava flour. Section 2 presents the design concept. The detailed design calculations are given in Section 3. The detailed mechanical drawings and the fabrication techniques used are in Sections 4 and 5. Finally, the results obtained when the fabricated flash dryer was installed and tested are given in Section 6.

Design concept

The objective is that the flash dryer system should be capable of producing industrial grade cassava flour or starch. The material to be handled could include grated and dewatered cassava mash, starch cake, and *fufu* cake

Out of these materials, the grated and dewatered cassava mash has the largest particle size. Consequently we have assumed that the raw material for the flash dryer is cassava mash in cake form. Hence, the material must be pulverized before it enters the flash tube.

Generally the drying agent can either be steam or air (Pakowski et al. 2004). We chose air for its availability and for the simpler and cheaper technology compared with steam generation. The source of heat energy would be diesel oil (AGO). However, the thermal properties of AGO are similar to those of spent oil. Hence a mixture of AGO and spent oil may be substituted for pure AGO. Also, the product must be of good quality, safe and suitable for human consumption: free from abnormal flavors and odor. To ensure these qualities, an indirect hot-air generator was used.

There are three types of flash tube configurations — positive pressure, negative pressure, and combined positive and negative pressures. The positive pressure configuration was chosen for this design. This will ensure that the materials and hot air do not go through the fan which would require a special design and selection of the material of construction for the fan, based on the harsh operating conditions. This also implies that the fan wheel will not damage the material and the fan does not experience any wear and tear from the material that may be deposited on the components of the fan (Engineering Data ED-3300). The negative system also requires a longer drying tube compared with the positive system. These decisions ensured a considerable savings in the construction cost.

To guarantee that the required amount of cassava cake is fed in at the right time, manual feeding and crushing of cassava mash were completely eliminated. Based on our experience from preliminary studies, we used the feeding mechanism consisting of a grater mechanism to pulverize the wet cake and a screw type feeder to give a good dosing/metering of the feed. The feeding system was designed to deliver 820 kg/h of dewatered cassava mash to the drying column. A rotary airlock was incorporated at the entrance to the drying duct to prevent the escape of hot air through the feeding system that could result in the backflow of pulverized materials.

The cassava particles need to be well dispersed in the drying duct. The feeding mechanism delivers the particles at the throat of a venturi incorporated before the drying duct.

The dried product is separated from the air stream in a cyclone. Since there is a need to recover almost all the dried product, the Stairmand high efficiency cyclone was chosen.

Using the above concepts, the block diagram for the proposed flash dryer is shown in Figure 2.

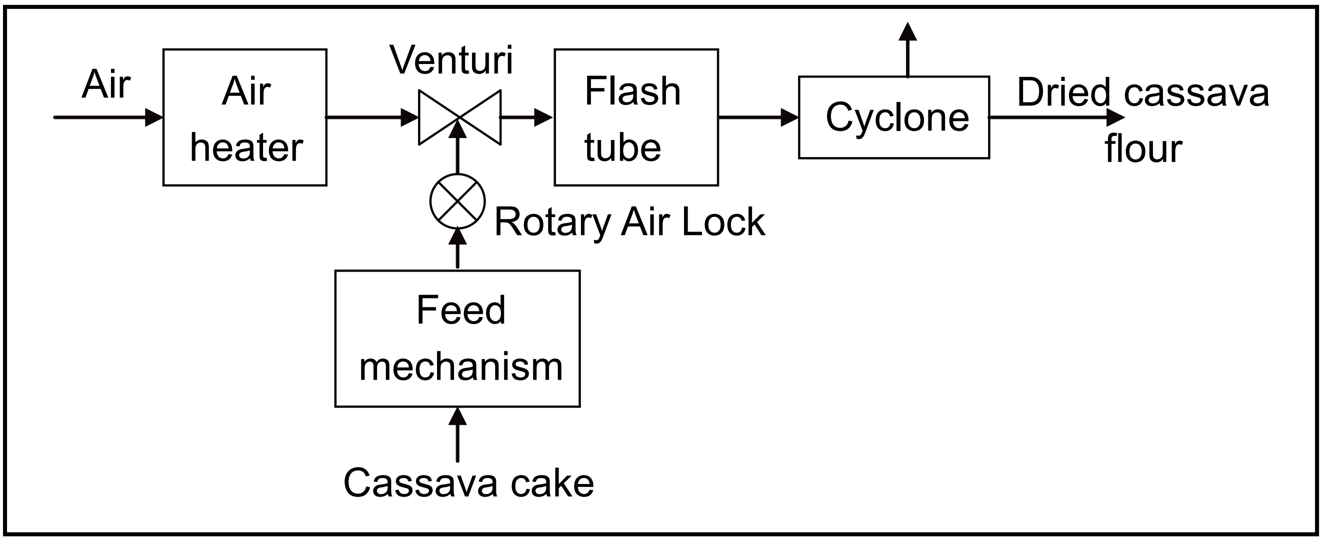

Figure 2. Block diagram of the Flash Dryer System.

Design calculations

Basis of the design
1 hour operation

a) Feed characteristics

Moisture content	=	45%
Cassava mash density	=	1380 kg/m^3
Feed rate	=	820 kg/h
Loading time	=	10 min

b) Product characteristics

Moisture content	=	10%
Output (from material balance)	=	501.1 kg

c) Flash tube

Temperature in the tube	=	180 ºC
Inlet air temperature	=	200 ºC
Largest particle size	=	1.5 mm
Particle density	=	491.7 kg/m^3
Ambient temperature	=	30 ºC

Notes:

1. The maximum moisture content for cassava products is 13% (Sanni et al. 2005). The moisture content of 10% in the chosen design gives an allowance for the possible rise in moisture content during storage.
2. Normally the temperature range within the flash tube is 100 ºC–650 ºC. (GEA-Barr-Rosin 2006).

Energy balance
For the flash drying system under consideration, the energy balance equation is stated as follows (McCabe et al. 1993): (3.1)

$$\frac{Q_s}{M_s} = C_s\left(T_p - T_f\right) + X_f C_{p,i}\left(T_v - T_f\right) + \left(X_f - X_p\right)\lambda + X_p C_{p,i}\left(T_p - T_v\right) + \left(X_f - X_p\right) C_{p,v}\left(T_{v,b} - T_v\right)$$

where

Q_s = Total heat transferred, J/s
C_s = Specific heat of dry solids, J/kg^{o}K
C_{PL} = Specific heat of pure water, J/kg^{o}K
C_{PV} = Specific heat of water vapor, J/kg^{o}K
M_s = Mass of dry solids, kg
T_p = Temperature of solids, ^{o}C
T_f = Temperature of feed, ^{o}C
T_v = Vaporization temperature, ^{o}C
T_{VB} = Final vapor temperature, ^{o}C
X_f = Moisture content of feed, kg moisture/kg dry solids
X_p = Moisture content of products, dry basis
l = Latent heat of vaporization (J/kg)

For our system

M_s = 492 kg
C_s = 1600 J/kg.K (Ademiluyi et al. 2005)

Barr-Rosin (2006) suggested that the normal range of temperature within the flash tube is 100–650 ºC. Also, the experimentally measured temperatures within the flash tube of two flash dryers at IITA were in the range of 160–180 ºC. Consequently, to ensure thermal stability of the cassava products, the solids temperature, T_p, is taken as 180 ºC.

T_f = 30 ºC
X_f = 0.45
C_{pl} = 4187 J/kg.K (Engineering Tool Box 2006a)
T_v = 100 ºC
λ = 2 × 10 J/kg
X_p = 0.1
C_{pv} = 1996 J/kg.K (Engineering Tool Box 2006a)
$T_{v,b}$ = 180 ºC (assumed to be at equilibrium with the solids)

Substituting these values for those in Equation 3.1 gives

$$\frac{Q_s}{M_s} = 1255.77 \times 10^3 \text{ J/kg}$$

$$Q_s = 61784.1 \times 10^3 \text{ J}$$

Also, $Q_s = M_a \Delta H$

where M_a = Mass of air
ΔH = Change in enthalpy of air = $H_o - H_i$
H_i = Enthalpy of air 30 ºC, 96% moisture
H_o = Enthalpy of air 180 ºC, 1% moisture

From Engineering Tool Box (2006 b, c)

H_i = 96774.05 J/kg and H_o = 374392.45 J/kg

Hence M_a = 2225.51 kg

r_a = Density of air at 200 ºC = 0.746 kg/m^3

V_a = Volume of air at 200 ºC = 2983.25 m^3

Flash tube

The flash dryer is basically a pneumatic dryer. Hence, the diameter and the length of the flash tube can be calculated using equations for a pneumatic column. The calculations are presented below.

Minimum carrying velocity, v_m

Minimum carrying velocity can be obtained from the relationship below (Perry and Chilton 1973):

$$V_m = 565.78\left(\left[\frac{\rho_s}{\rho_s + 997.95}\right]D_2^{0.6}\right) \quad (3.2)$$

where D_2 = Diameter of largest particle to be conveyed

Therefore V_m = 3.7096329 m/sec

To prevent settling, the actual velocity is multiplied by a factor to obtain the Actual Carrying Velocity. Assuming a factor of safety of 1.1, we have:

$V_{actual} = V_m \times$ factor of safety

$= 4.0805962$ m/sec

Duct internal diameter

$V_s =$ Volume of solids

$= M_s/\rho_s = 1.0006101\ m^3$

Hence the total volume is

$V_t = (V_a + V_s) = 2984.2508\ m^3$

and volumetric flow rate is

$Q = V_t /3600 = 0.8289586\ m^3/s$

The pipe diameter is obtained by using the equation given by Avallone and Baumeister (1987):

$$ID = 0.6392\sqrt{\frac{Q}{v}} \tag{3.3}$$

where ID = Internal diameter (inches)

v = Flow velocity (ft/sec)

Hence, ID = 20.024787 inches = 508.62958 mm

Equivalent length

$$L = V_{actual} \times \text{Residence time} \tag{3.4}$$

The maximum residence time of particles in a flash dryer is 3 seconds (Christiansen and Sardo 2001). For our design we have used 1.5 seconds.

Hence, L = 6.1208943 m

By design, the entry into the flash dryer is horizontal; hence the duct bending curves have to be determined. From Avallone and Baumeister (1987), the bend radius, R = 3 × ID

That is, R = 1525.8887 mm (3.5)

Feeding system

The feeding system is made of the following major components: hopper, pulverizer, screw conveyor, and a rotary air lock. The rotary air lock ensures that there is no back flow of materials since we are using the positive pressure configuration for the flash dryer.

Hopper capacity

The hopper capacity H_c can be obtained from the following equations, using a factor of 10% additional volume added on to the calculated hopper volume to avoid spillage.

$$H_c = 1.1\left[\frac{F_r t_r}{\rho_b 60}\right] \quad (3.6)$$

where

F_r = Feed rate, kg/h

t_r = Residence time, min

ρ_b = Bulk density of mash, kg/m^3

With a bulk density of 1380 kg/m^3, a feed rate of 820 kg/h (20.976 ft^3/h) and assuming a loading time of 10 minutes, the hopper volume is 0.108 m^3.

Hopper Dimensions

The volume of a frustum (conical, pyramidal or other forms) is given by Weisstein (2006):

$$V = \frac{h}{3}\left(A_1 + A_2 + \sqrt{A_1 A_2}\right)$$

where A_1 is the area of the bottom surface, A_2 the area of the top surface, and h the height. For this work, we have chosen a modified pyramidal form (see Figure 3). The volume is given by:

$$V = h_1 A_1 + \frac{h_2}{3}\left(A_1 + A_2 + \sqrt{A_1 A_2}\right)$$

$$A_1 = W_1 L_1,\ A_2 = W_2 L_2$$

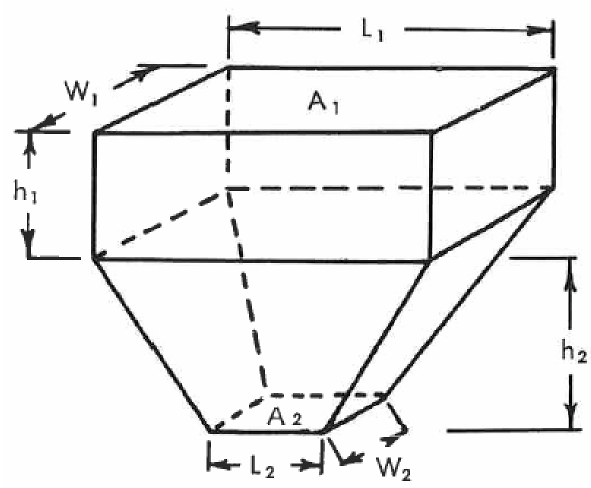

Figure 3. Hopper.

The slopes of the hopper bottoms must be steeper than the angle of repose of the material stored. The limiting angle is the valley angle, the angle between the joint of the sloped bottoms and the horizontal angle, C (Figure 4). Knowing the angles of the hopper bottoms, A and B, the angle C can be calculated from FEECO Handbook (2006):

$$\text{Cot}^2 C = \text{Cot}^2 A + \text{Cot}^2 B \quad (3.9)$$

Using equations 8 and 9, the dimensions for the hopper are:

W_1 = 0.5	W_2 = 0.32	L_1 = 0.5	L_2 = 0.22
h_1 = 0.1	h_2 = 0.555795744		
A = 76°	B = 81°	C = 70°	

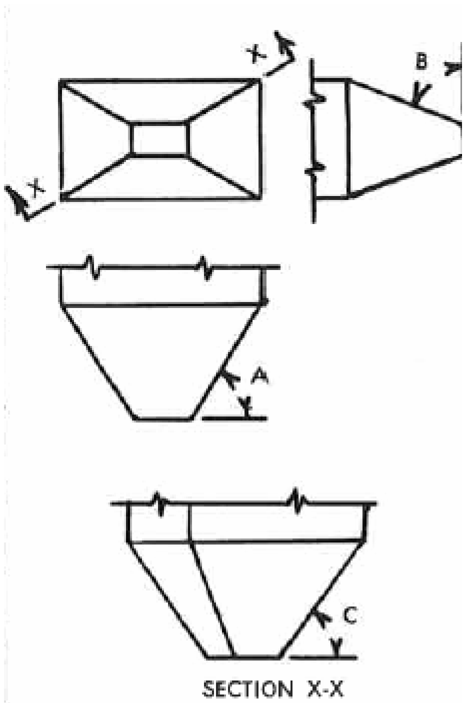

Figure 4. Hopper sections.

Pulverizer

Type: the grater surface type presently in use at the IITA was selected. This breaks up the lump of mash formed after the dewatering process. The grater specifications are:

Drum diameter = 200 mm

Length = 285 mm

Power requirement = 5 hp motor

Max. speed of motor = 770 rpm

Screw conveyor

The Martin's Screw conveyor chart is used. The relevant tables are given in Annex A.

Cassava cake is not listed in the Martin's Screw manual. Hence, we have assumed that cassava cake is similar to wet sugar beet pulp. The material characteristics for the sugar beet are shown in Table 1.

Table 1. Material characteristics.

Characteristic	Value	Remark
Material size	C½	Particle size is < ½ in
Flowability	3	Average flowability
Abrasiveness	5	Mildly abrasive
Other characteristics		Packs under pressure
Trough loading	30%	30A in Table A2
Hp factor (F_m)	1.2	

From Table A1, the hanger bearing type is L-S-B: hence, from Table A3 the ball bearing type coupled on a standard shaft is selected, giving a hanger bearing factor (F_b) of 1.0. A1 A3

At 30%A, from Table A4, for a screw diameter of 4 in (100 mm), the capacity (full pitch) @ 1 rpm is 0.41 ft^3/h and @ max. rpm (130 rpm for 4 in), the capacity (full pitch) is 53 ft^3/hr. A4

Screw power design

The power required to drive the screw can be calculated as the sum of the power required to overcome friction (P_f) and the power required to transport the materials (P_m). The total power requirement is calculated by introducing the overload factor and the drive efficiency. These components are given as:

$$P_f = \frac{LNF_dF_b}{1{,}000{,}000} \quad (3.10)$$

$$P_m = \frac{CLWF_fF_mF_p}{1{,}000{,}000} \quad (3.11)$$

$$P_T = \frac{(P_f + P_m)F_o}{E} \quad (3.12)$$

where

L = Total length of conveyor, ft

N = Operating speed, rpm

F_d = Conveyor diameter factor (See Table A5) A5

F_b = Hanger bearing factor (See Table A6) A6

The 1,000,000 is a factor that is related to the type of unit used.

C = Capacity, ft^3/h

W = Weight of material, lbs/ft^3

F_f = Flight factor (See Table A7) A7

F_m = Material factor (See Table A2) A2

F_p = Paddle factor, when required. (See Table A8) A8

F_o = Overload factor (See Table A9) A9

E = Drive efficiency (See Table A10) A10

Choosing a length of 1000 mm (3.28 ft) for the feed conveyor, the conveyor diameter factor for a 4 in (100 mm) shaft is 12 from Table A5 and the hanger bearing factor is 1.0 (for a short shaft using ball bearings at ends only) (Table A6). The weight (per unit volume) is 1380 kg/m^3 (86.150 lb/ft^3). From Table A7, the standard flight factor for 30% loading is 1.0. and from Table A2, the material factor at a conveyor loading of 30% with a standard flight type is 1.2.The capacity (full pitch) at 1 rpm is 0.41 ft^3/hr and at max rpm (130 rpm) for 30% loading it is 53 ft^3/h .
The required speed is therefore the ratio of the volumetric flow rate to the capacity at 1 rpm (20.976/0.41) giving 51.16 rpm. This is approximated to 55 rpm.

From the foregoing,

$$P_f = \frac{LNF_dF_b}{1,000,000} = \frac{3.28 \times 55 \times 12.0 \times 1}{1,000,000} = 2.164 \times 10^{-3} Hp \quad (3.13)$$

$$P_m = \frac{CLWF_fF_mF_p}{1,000,000}$$

$$= \frac{20.976 \times 3.28 \times 86.15 \times 1.0 \times 1.2}{1,000,000}$$

$$= 7.113 \times 10^{\;3} Hp$$

From Table A9, the overload factor is 3. The drive efficiency factor for the screw drive shaft mounted on a V-belt drive is 0.88 (Table A10), therefore;

$$P_T = \frac{(P_f + P_m) F_o}{E} = \frac{9.277 \times 10^{-3} \times 3}{0.88} = 0.03 Hp \quad (3.14)$$

The final screw conveyor and its dimensions are shown in Figure 5.

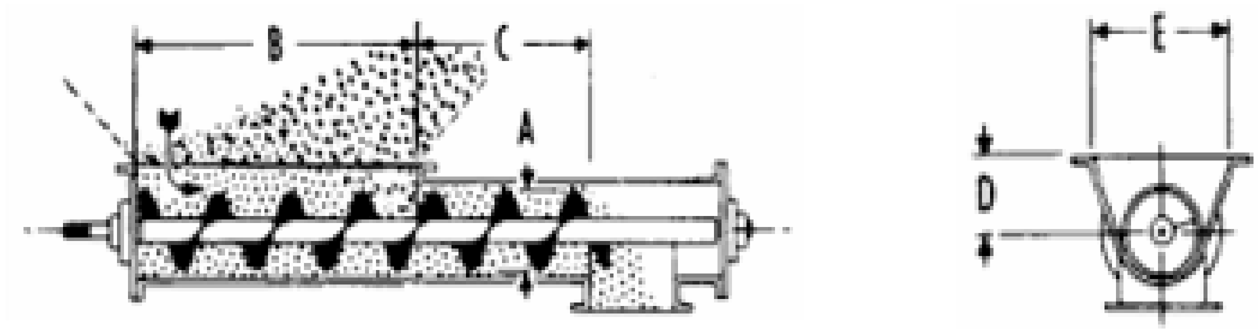

Figure 5. Screw conveyor and its dimensions.

A = 100 mm, B = 300 mm, D = 125 mm and
L = 1000 mm

Feed mechanism connection

At the feed point, the particles must be mixed properly with the incoming hot air. One way of achieving this is to increase the velocity (by implication, reduce the pipe diameter) at the feed point. To achieve this objective we have adopted the standard Herschel-type venturi (Perry and Chilton 1973). Its proportions are as follows.

- Entrance cone angle, α_1 = 21 ±2°
- Exit cone angle, α_2 = 5 – 15°
- Throat length = one throat diameter

The actual dimensions using our pipe diameter are as shown in Figure 6.

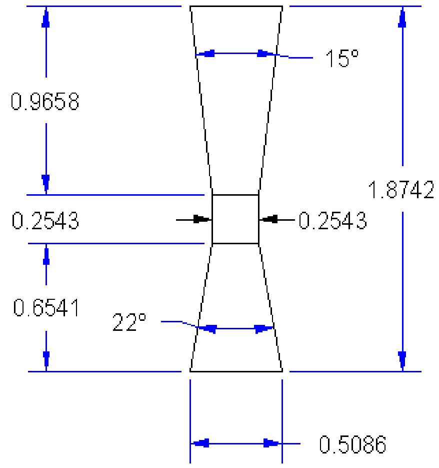

Figure 6. Venturi dimensions.

The screw feeder continually feeds material into the venturi. In locating the venturi, there are two options, (i) vertical arrangement or (ii) horizontal arrangement. With the vertical arrangement, the bearing at the discharge end will be exposed to excessive heat and there is also the fear of contamination from the lubricant because the bearing has to be inside the connecting pipe to be able to carry the discharge end of the screw. For the horizontal venturi arrangement, the feeder drops the material through the air stream and so entrainment is as good. Also the bearing at the two ends of the screw feeder can be placed outside and away from the heat of the drying air stream. The horizontal venturi arrangement is used and is as shown in Figure 7.

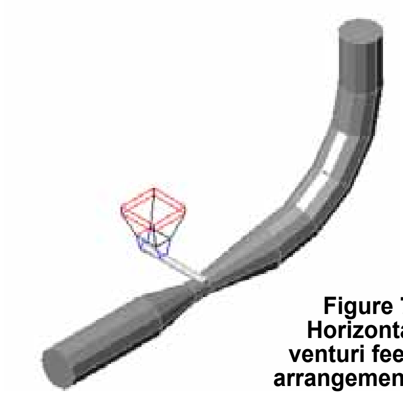

Figure 7. Horizontal venturi feed arrangement.

Cyclone

There are many standard configurations available for cyclones. For the flash dryer, we require that a minimal amount of the dried product should be entrained in the gas outlet. Hence, we have chosen the Stairmand High Efficiency configuration. This is shown in Figure 8.

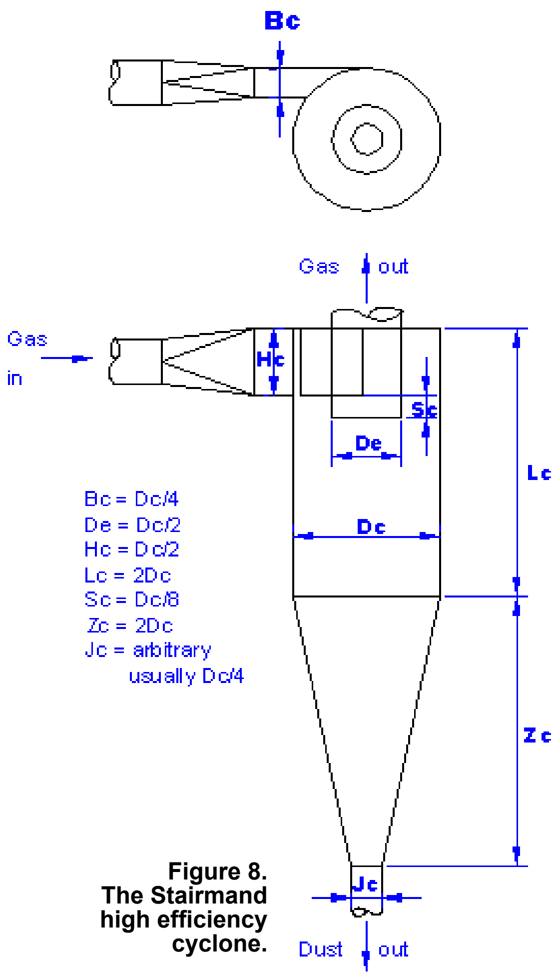

Figure 8. The Stairmand high efficiency cyclone.

As can be seen, the dimensions are dependent on the cyclone diameter D_c.

To design the cyclone, the RMRDC CAPED Software (Kuye et al. 2004) was used. The input data required by the software are as stated below:

Geometry	Stairmand HE	
Model	Leith & Licht	
Temperature	180	°C
Pressure	101325	N/m^2
Gas	Air	
Particle density	491.7	kg/m^3
Maximum particle size	1500	microns
Minimum particle size	200	microns
Dust loading	164.8654978	g/m^3
Feed rate	0.828958566	m^3/s
Cyclone diameter	0.678625476	m

The output generated by the software is stated below:

Diameter, Dc	0.581140138 m
Inlet height, a_c	0.290570069 m
Inlet width, b_c	0.145285035 m
Outlet diameter, De	0.290570069 m
Gas outlet length, S	0.290570069 m
Cylindrical height, h	0.871710207 m
Conical height, Zc	1.452850346 m
Total height, H	2.324560553 m
Dust outlet diameter, B	0.217927552 m

Discharge

The entrainment will be collected by a dust trap fitted with a vortex shield. The size of the dust collector will be determined by the quantity (Fig. 9) of processed material collected per unit time. The capacity of the dust trap is made to correspond to the volume of material processed in 10 minutes.

Determination of dust trap dimensions

Product throughput (mass basis) = 500 kg/h

Product throughput (volume basis) = 1.0006101 m^3/h = 1.000610/6 m^3/h = 0.168 m^3/h

The dimensions of the dust trap are as shown below:

a	0.55	m
b	0.34	m
c	0.6	m
d	0.3	m
Volume	0.168418	m^3

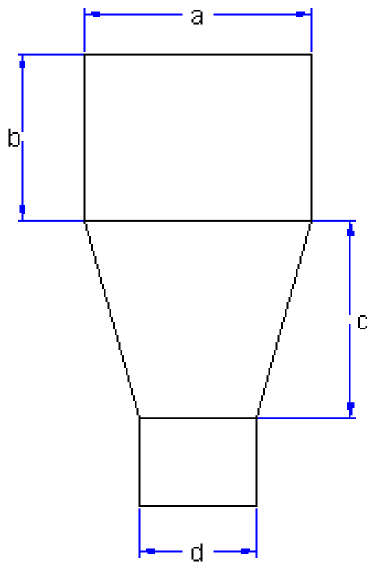

Figure 9. Dust trap.

Heat exchanger

The heat exchanger is required to provide enough heat for air to dry the mash. A section of the proposed heat exchanger is shown in Figure 10. As can be seen, it is effectively an arrangement of two concentric tubes. Also, for ease of fabrication, the circumferences of the inner and outer tubes are made to correspond to the short and long sides of a standard 2438.4 mm × 1219.2 mm metal sheet. The following assumptions were made.

1. Heat transfer is by convection
2. Heat would be supplied by a diesel-fired burner
3. Adiabatic flame temperature of diesel is 2138 °C. (www.kanabona.com/www/?q=burners_flames)
4. Exhaust air temperature for diesel fuel combustion is 600 °C (www.engineeringtoolbox.com/fuels-exhaust-temperatures-d_168.html)
5. Inlet and outlet air temperatures are respectively 30 °C and 200 °C

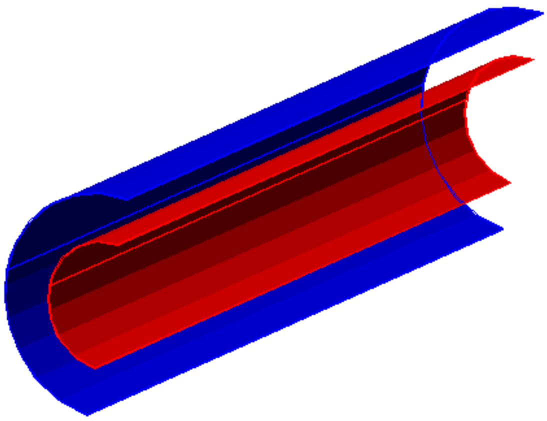
Figure 10. Heat exchanger model (section).

The heat transfer equation is:

Heat load (from energy balance equation) = Heat transferred by convection (3.13)
Using equation 3.13 and appropriate correlations from McCabe et al. (1993) we have

L_H = 2.24 m

The length of a standard metal sheet is 2438.4mm, hence, the heat exchanger length is taken as 2.438 m. This is long and to make the exchanger compact, the heat exchanger will be made to have two passes.

Fan specification

As stated in Section 2, our flash dryer system uses the positive displacement method. The fan horsepower must be chosen to ensure that it can overcome at least the pressure drop across the flash dryer. For pressure calculation purposes the main components are:

1. Pressure drop across the heat exchanger
2. Pressure drop across the flash tube
   - Pressure drop upstream of the venturi
   - Pressure drop across the drying duct (horizontal pipe)
   - Pressure drop across the venturi
   - Pressure drop across the drying duct (vertical pipe and 90 degrees bend.)
3. Pressure drop across the cyclone
4. Pressure drop across the cyclone discharge hopper

Using Bernoulli's equation and other pertinent equations the total pressure drop across the system is
P_T = 2075.893 Pa
and the corresponding horsepower is
Hp = 1720.83 W
Assuming an efficiency of 70%
Fan Power Hp = 2458.33 W 3.5 Hp

Design drawings

Introduction

The production of machine drawings in components and their assembly during the processes of design and fabrication of machines have been made very easy with the availability of 3D CAD software having capabilities for animation. A combination of three types of CAD software, AutoCAD, AutoDesk Inventor, and Solidworks, was used in the components and assembly drawings in this work. The capability of scripting and auto-dimensioning which makes modifications possible without going through the trouble of redrawing as in the traditional methods made these applications very helpful. The 3D solid figures and the 2D orthogonal drawings of the dryer and the components are presented in this section.

For convenience, we have divided the flash dryer system into four segments:

1. Blower and heat exchanger
2. Feeding system
3. Venturi section
4. Cyclone and discharge

The drawings for the components above are given in Figures 12–23. The complete flash dryer system is shown in Figure 11.

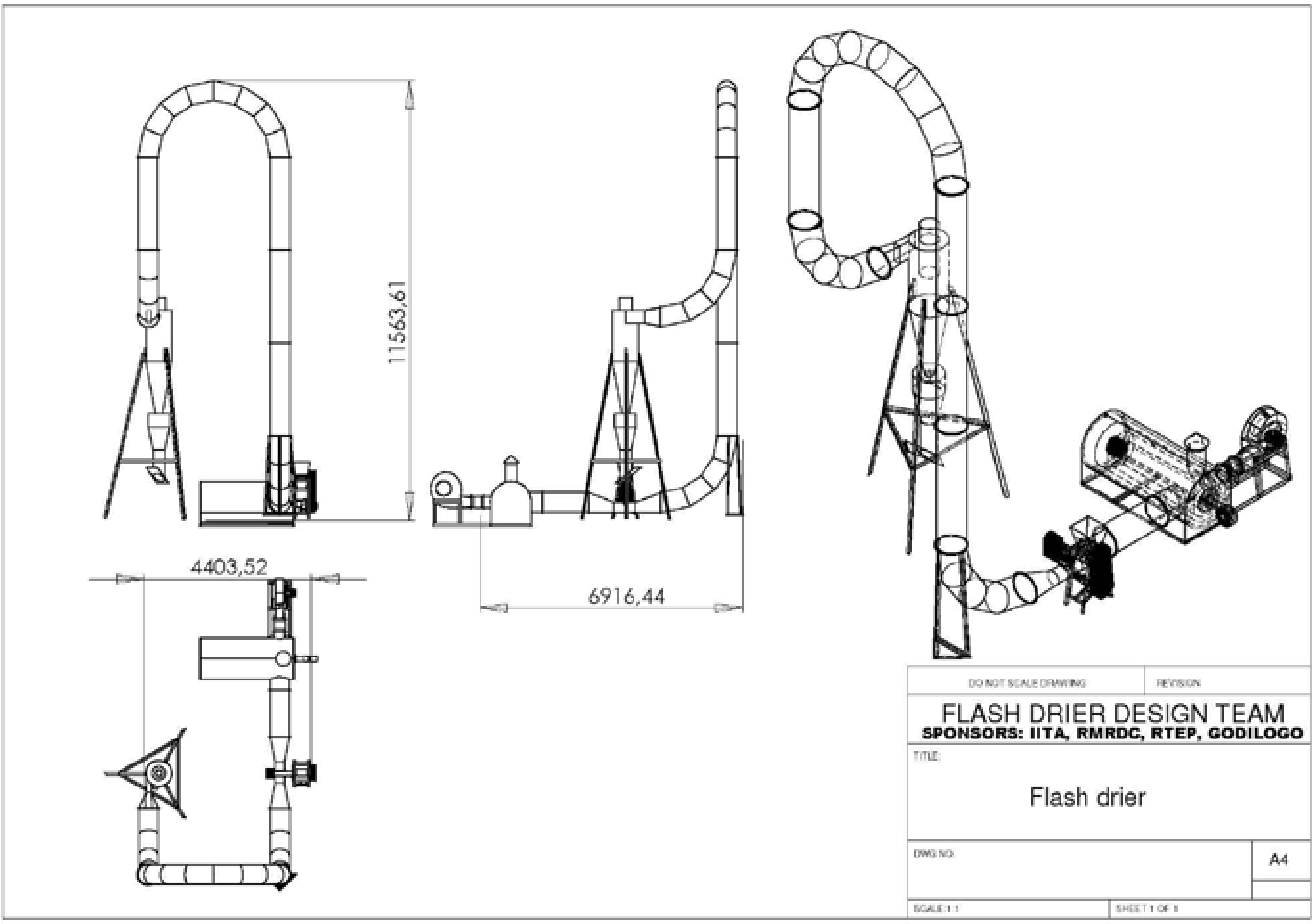

Figure 11. Complete Flash Dryer system.

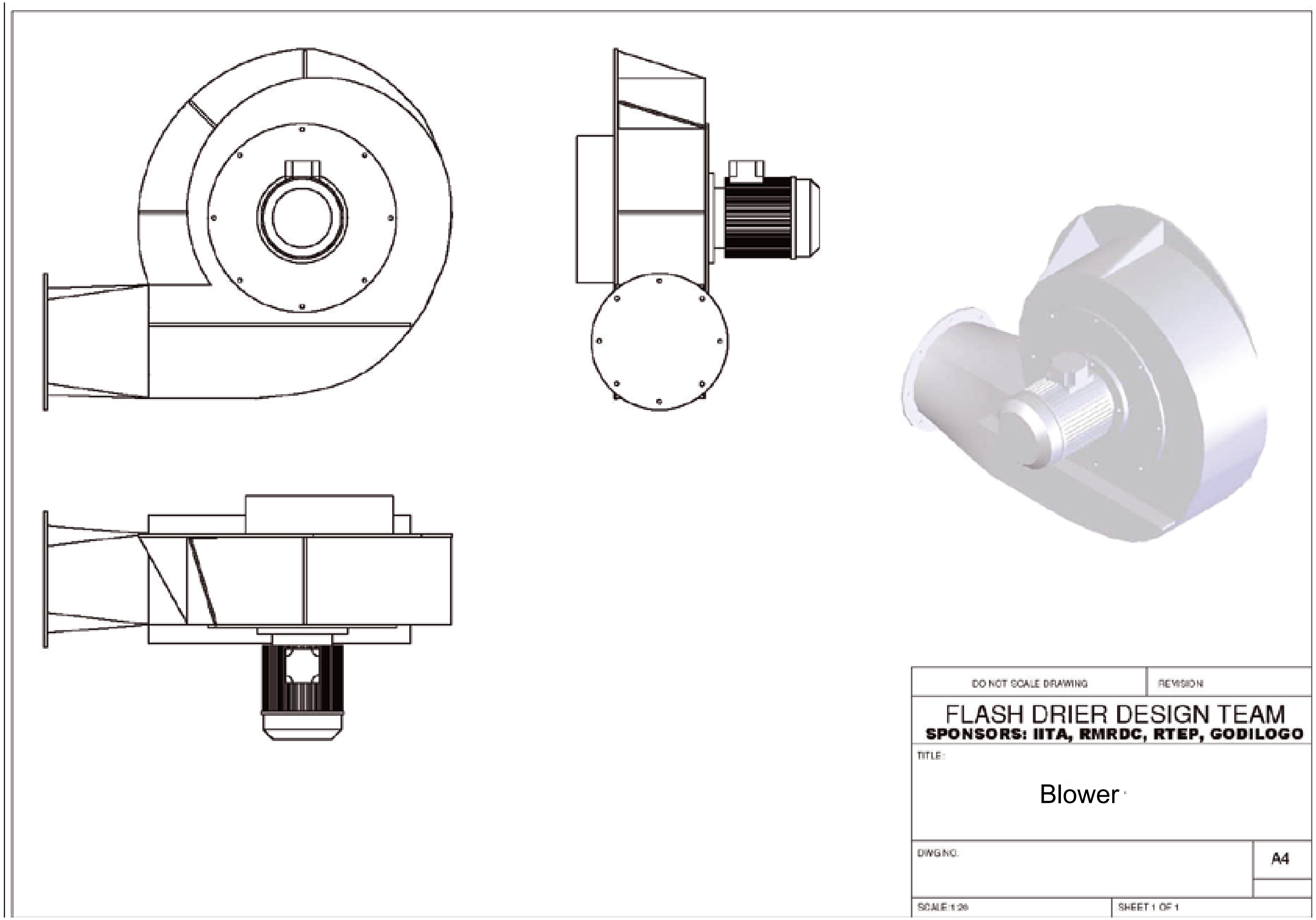

Figure 12. The air blower.

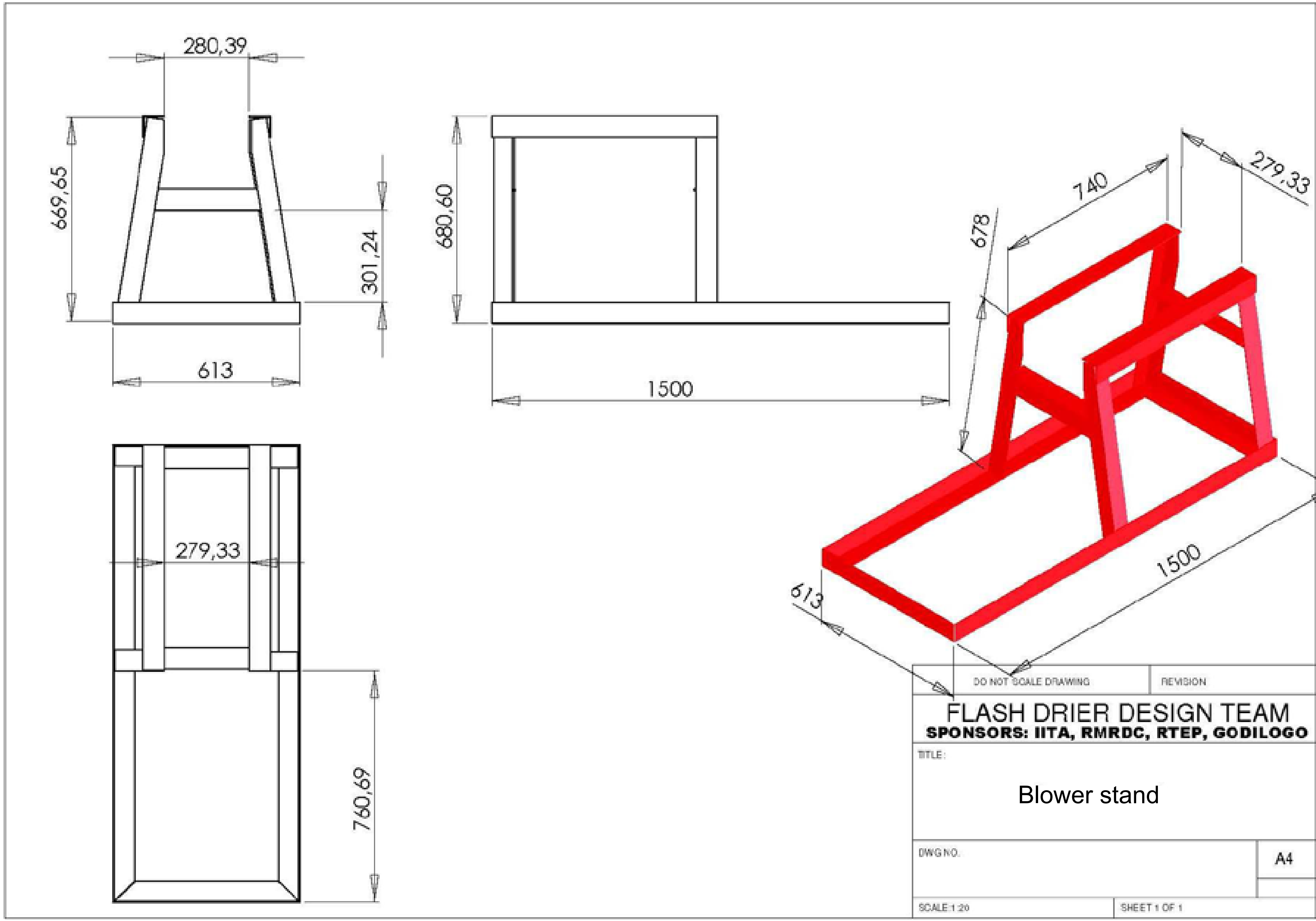

Figure 13. Support for the blower.

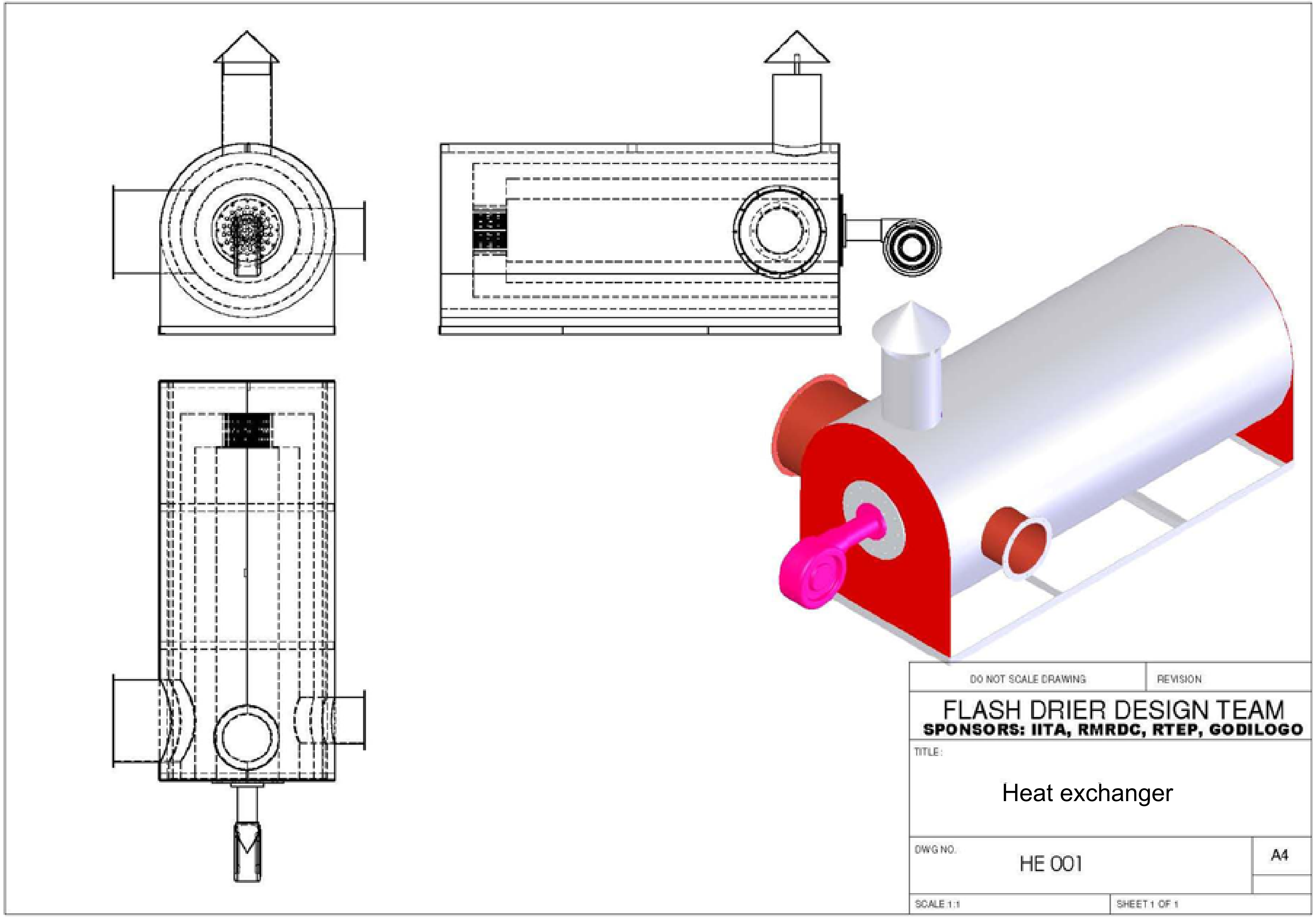

Figure 14. Fired tube heat exchanger.

Feeding System

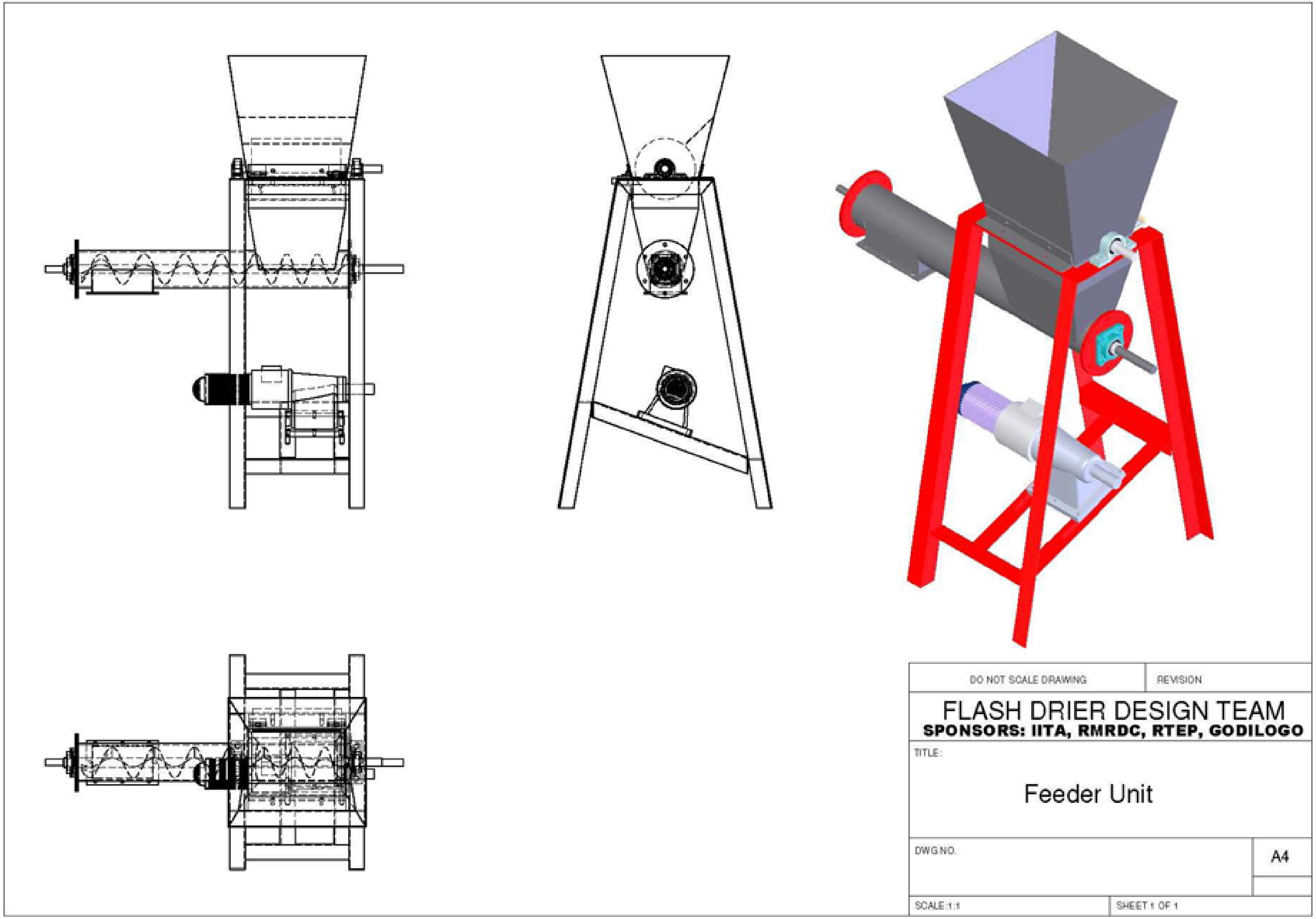

Figure 15. Feeding system.

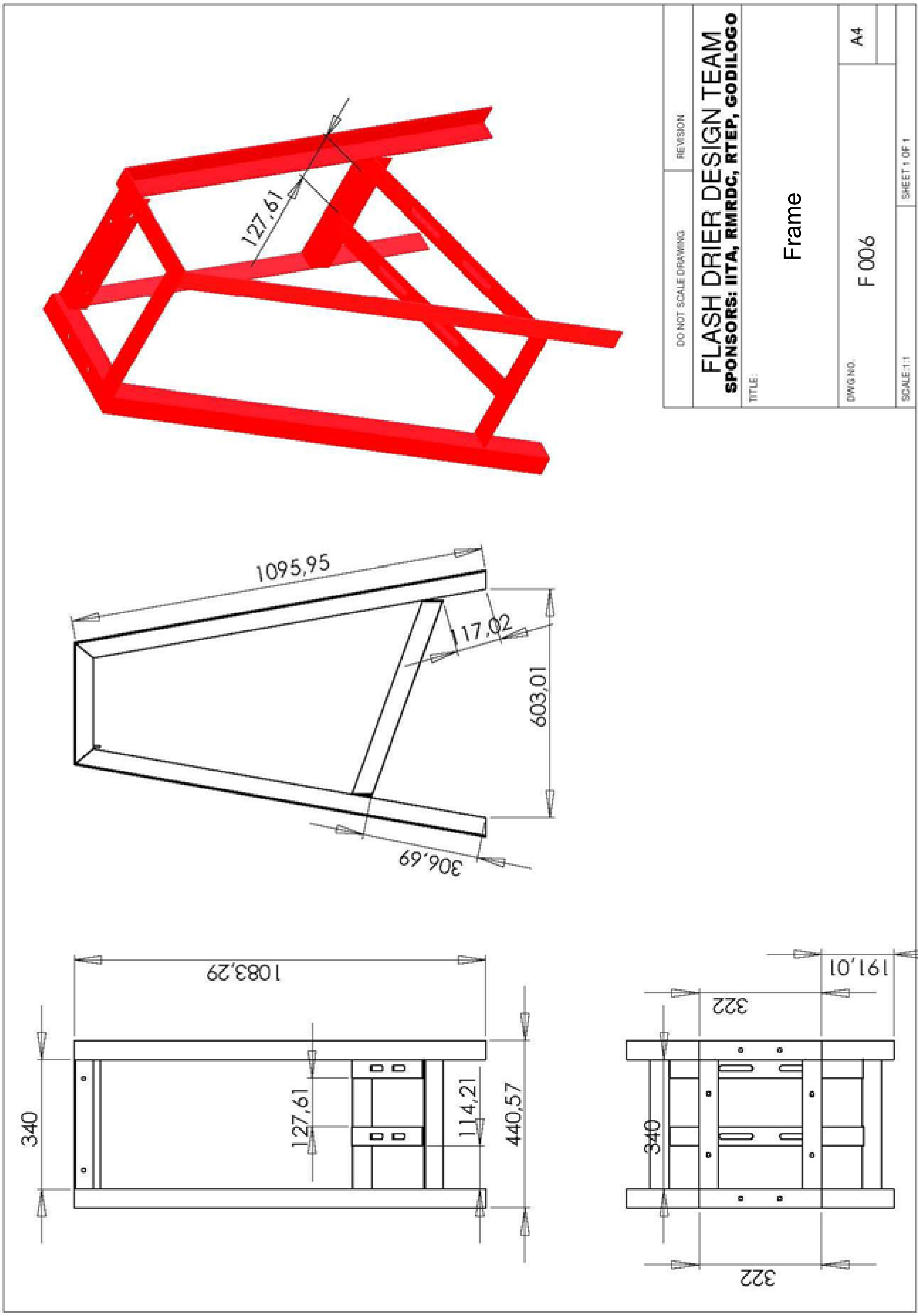

Figure 16. Frame for the feeder unit.

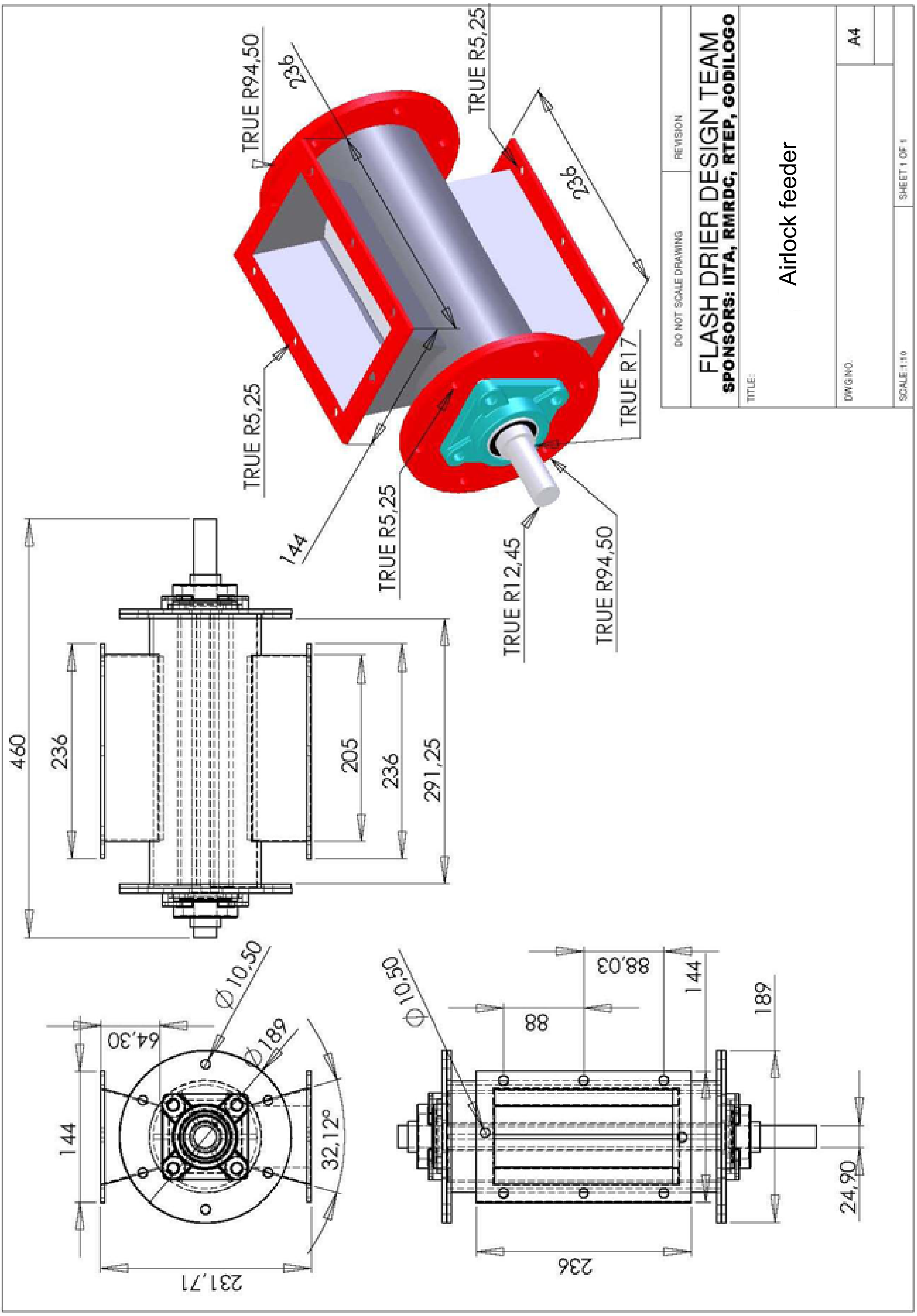

Figure 17. Air lock unit.

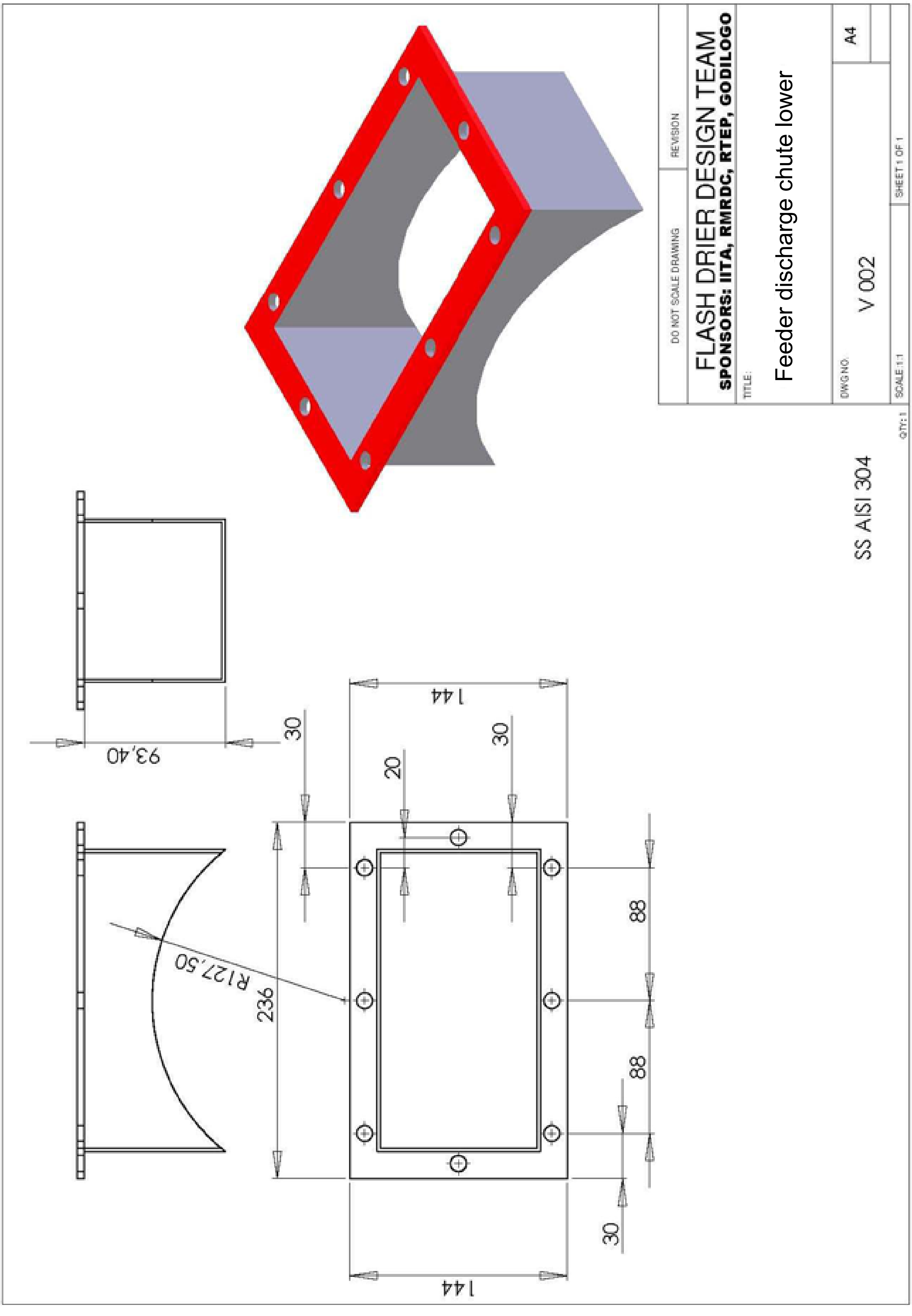

Figure 18. Feeder discharge chute.

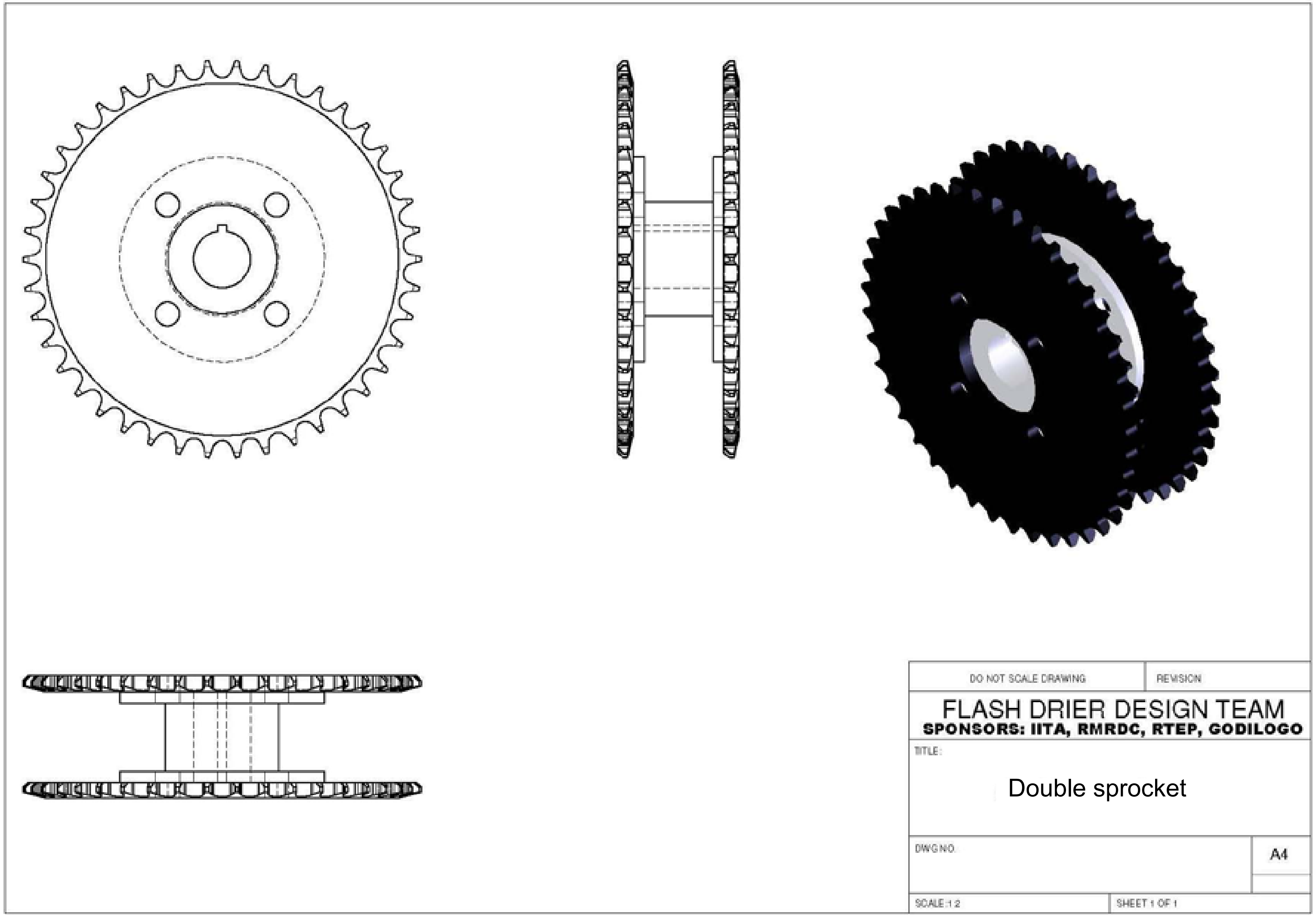

Figure 19. Double sprocket.

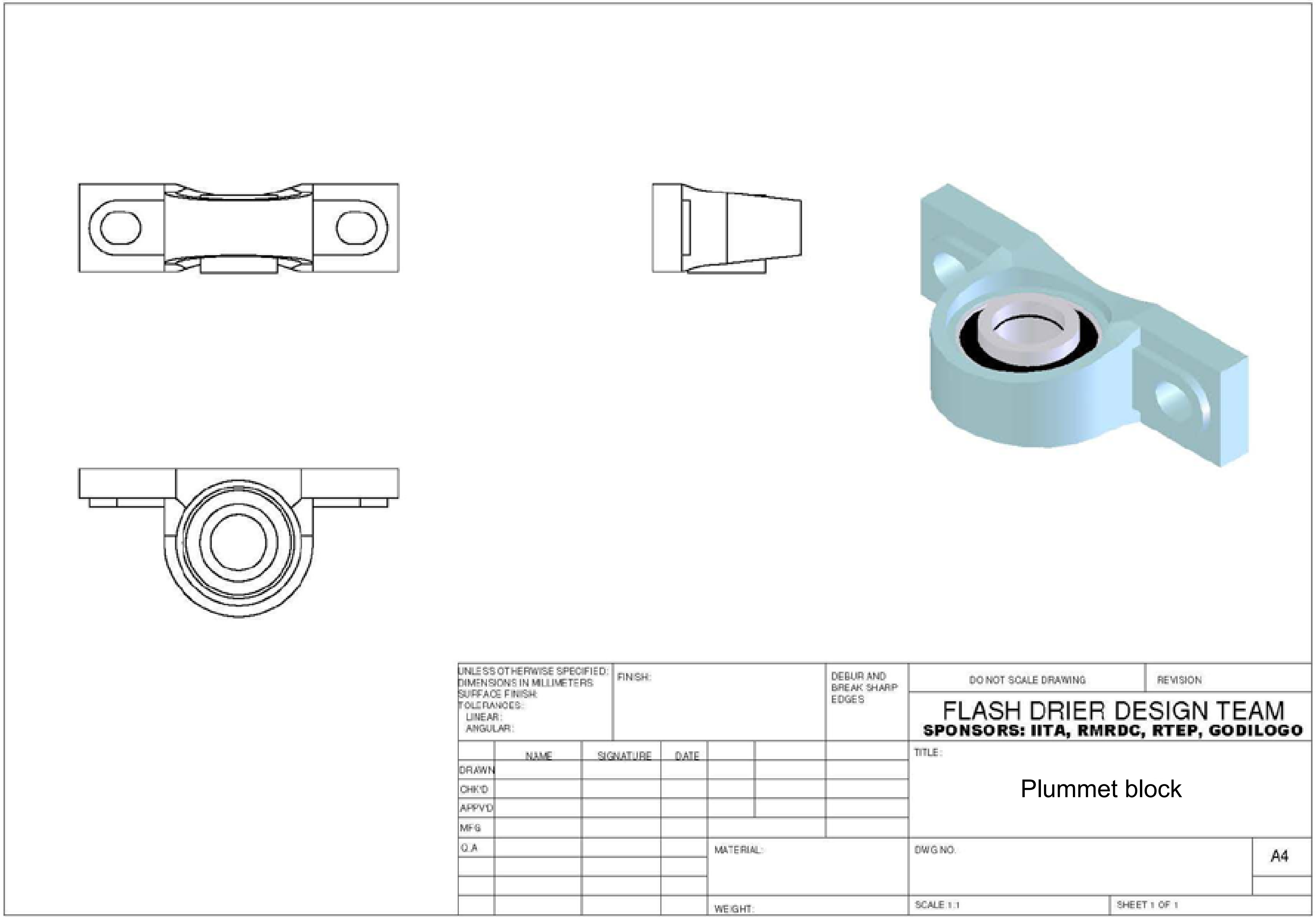

Figure 20. Plummer block.

Venturi Section

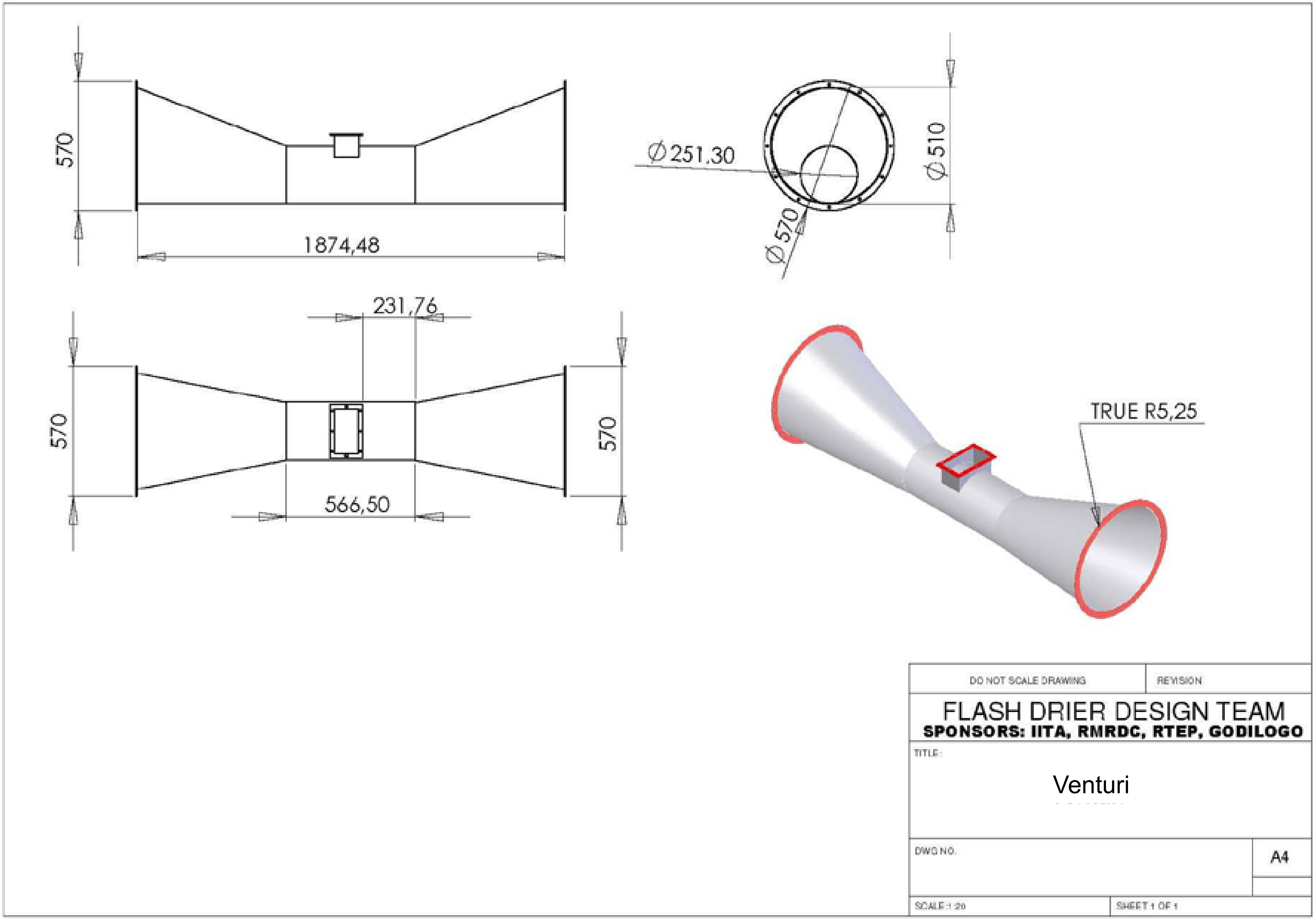

Figure 21. Venturi.

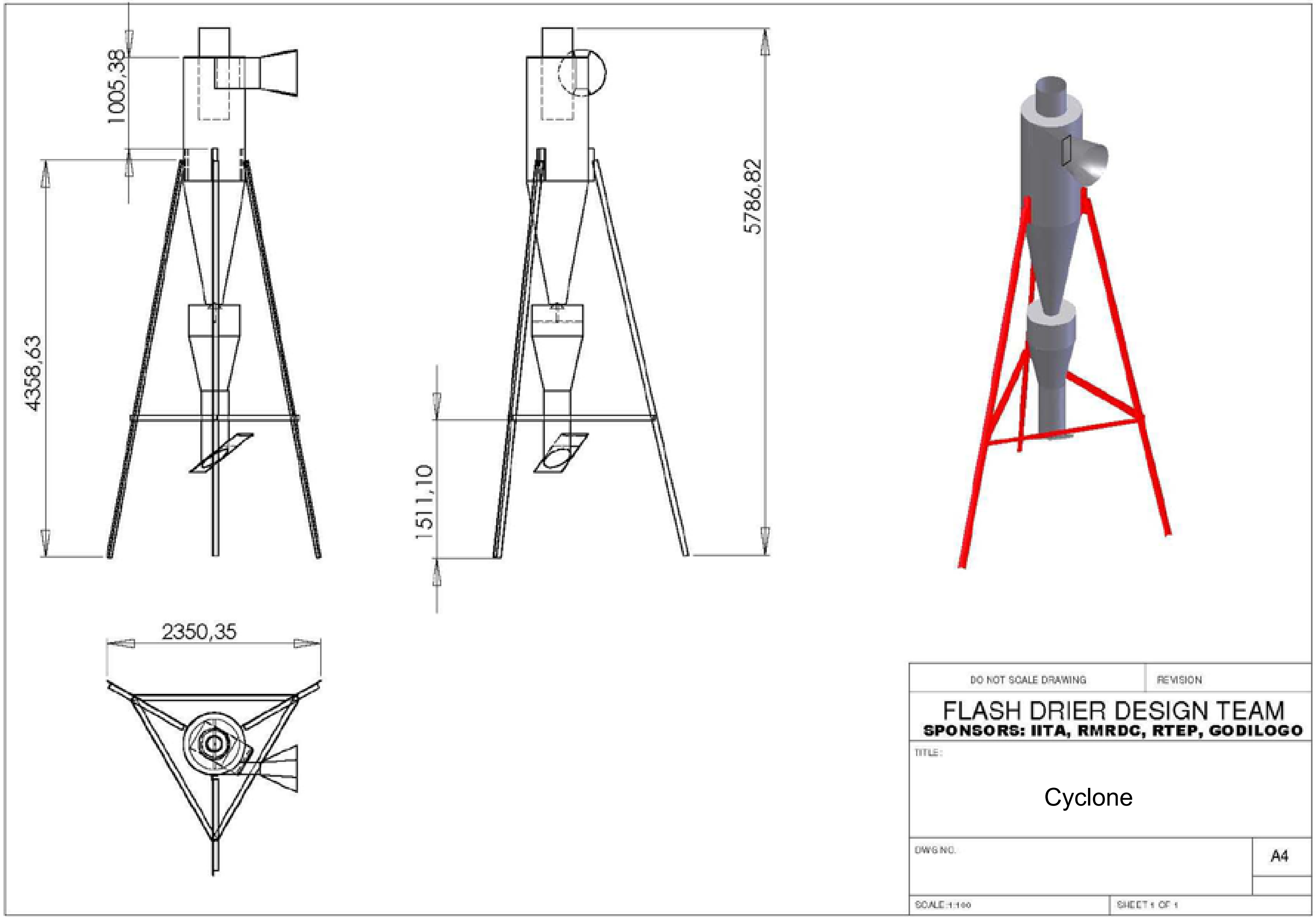

Figure 22. Cyclone and discharge with support.

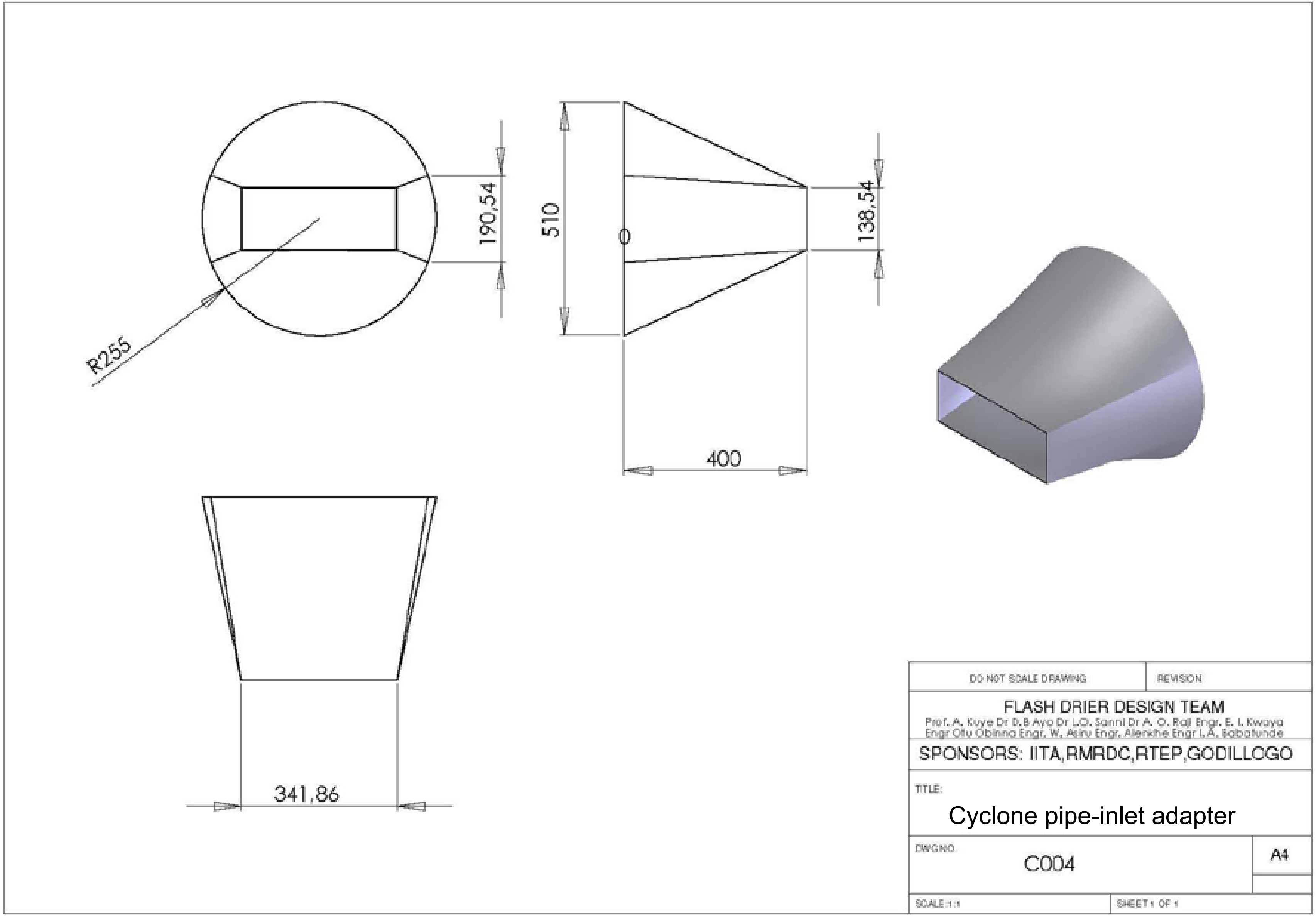

Figure 23. Cyclone inlet pipe adapter.

Flash Dryer Fabrication

Introduction

The fabrication of processing equipment in most developing countries is fraught with problems. The present practice involves mainly reproducing existing designs and fabricating these without the knowledge of the principles guiding the choice of components and their dimensions. The lack of appropriate tools and machines is also a limiting factor for the fabricators. The resulting machines are usually functional but with low efficiency, requiring frequent maintenance as a result of wear and tear caused by eccentricity amongst other causes. The machines are often noisy, ineffective, and without good finishing and appearance.

The team designed the flash dryer from first principles and determined all dimensions and other design requirements based on laid-down principles. The next steps were producing the components and assembling these to form the flash dryer.

Fabrication Techniques

The team encountered many challenges during fabrication and had to employ extensive improvisation to produce the components without compromising quality and aesthetics. Angle grinders with a cutting disc were used to do all metal cutting in place of a guillotine. The components were marked accurately and the cut was made to follow the line. There was also no edge bender to bend the development of sections such as the rectangle to circle transition. The cutting disc on the angle grinder was used to make light cuts on the bend lines before these were bent using an improvised jig. The light cuts made the regions along the bend lines bend easily, facilitating the assembly of the development. The bending roll that was used for the fabrication of the flash dryer was produced locally and so it had no settings. This means that the extent to which the machine would roll a component was not known except by trial. The team fed the sliding roll gradually while monitoring the curvature until it closed.

A more serious challenge with rolling arose in the development of a truncated cone. Again, improvisation came to the rescue and the component was produced successfully.

There was no sprocket available in the market with the right specification for the designed diameter of the drive sprocket. This meant that there was a need to produce a sprocket of the required diameter which must run on the chain provided. CAD software was used to generate the tooth profile but the right hobbling machine was also not available and so the sprocket was produced by marking out, drilling, and filing off the excess material.

Another major challenge encountered was the difficulty in the production of special shapes, profiles, and transitions. The team used software in the appropriate design, drawing, and fabrication of machine-component parts for the flash dryer. Off-the-shelf software was used with special capabilities for the application of engineering parameters in component design.

Drawings and 3D models of the components, sub-assemblies, and complete machine assembly were produced using two CAD applications: Autodesk professional and Solidworks. A profile development software, Plate'n'Sheet, was used to create the templates for the components. The templates were exported from Plate'n'Sheet to AutoCAD where appropriate dimensioning-to-fit was done for printing.

The resulting machine when completed was aesthetically sound, a demonstration of the power of computer assistance in fabrication, and of first-class craftsmanship. The machine operated at the designed efficiency, with minimal vibration and noise levels well within the acceptable limit. These were measured and compared with those from two similar, existing machines within the same factory. Figures 24 to 31 show how some of the special components were produced using the techniques enumerated in this section. The Bill of Quantities is given in Annex B.

Figure 24. Cutting-out the intersection point of the air inlet manhole into heat exchanger ring 3 using an angle grinder.

Figure 25. Cut-out development of the cyclone inlet.

Figure 26. Assembling the cyclone-transition to the cyclone-inlet.

Figure 27. Rolling the exchanger rings on a locally fabricated bending roll.

Figure 28. Improvised set-up for finishing off the rolled cyclone-taper-body.

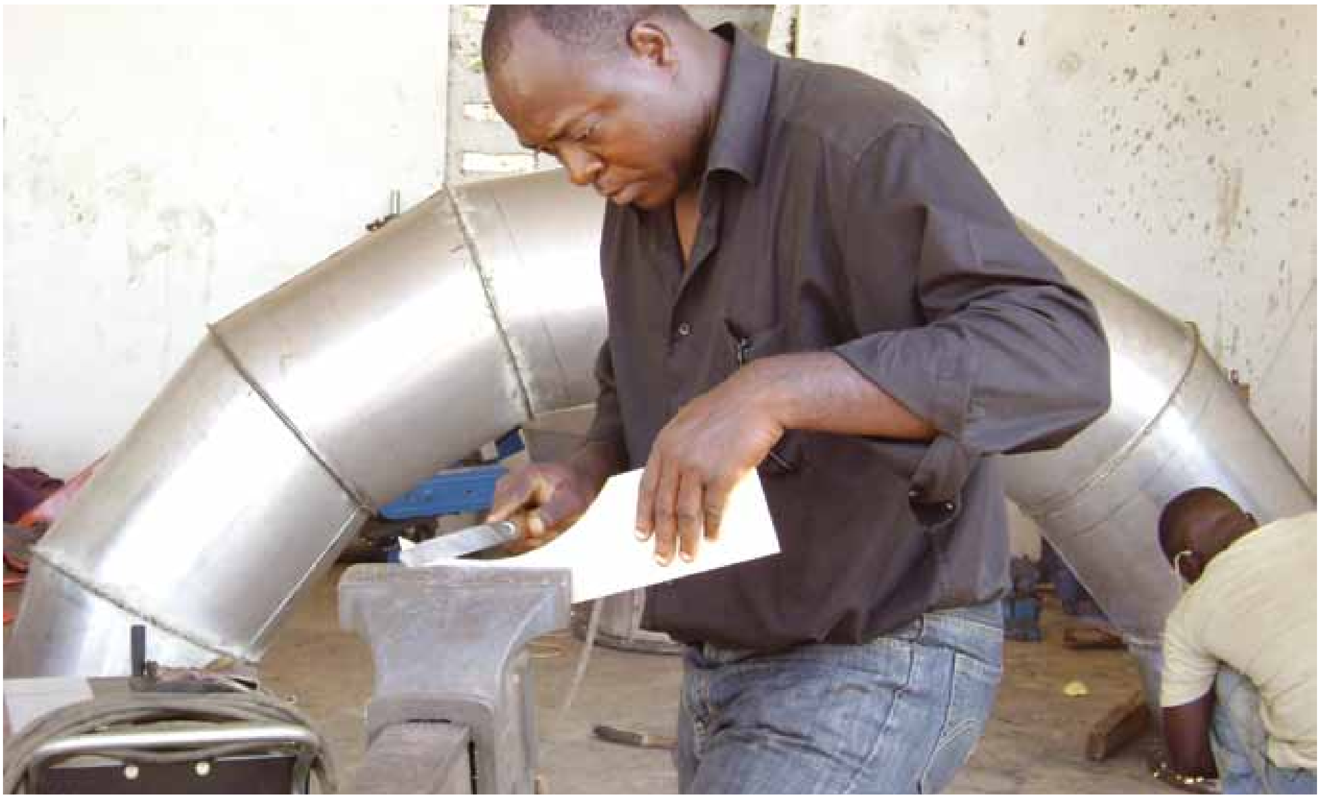

Figure 29. Improvised set-up for finishing off the rolled cyclone-taper-body.

Figure 30. Filing down the development of the feeder-discharge-chute.

Figure 31. Machining the screw feeder to fit the feeder barrel.

Motor control center (MCC)

The previous way of handling motion control was to choose an off-the-shelf motor controller with ratings that usually exceeded the actual application requirements. However, the performance demands made on today's motion-control systems frequently eliminate off-the-shelf products from consideration. These demands concern high rates of acceleration and deceleration, tight speed accuracies, and fine increments in adjustment that are difficult to obtain using collections of standard products.

For this flash dryer, a motor control center (MCC) system was designed and off-the shelf components were assembled according to the designed specification. The MCC incorporated a mimic panel with LED display showing the various operating states of the plant. A central emergency stop was provided on the MCC to shut down the entire plant in an emergency.

Rather than make do with standard parts, the design of the MCC and motor selection were carried on together as an optimized system. This technique involved constructing a motor from a few building block components and matching it with a power supply and motor controller components that together provided the needed performance at a minimum cost. Several safety features were incorporated: all components have overload and phase failure indicators; the blower is interlocked with the heat exchanger burner; the pulverizer is interlocked with the feeder to avoid overfilling the feed system.

The external feature of the MCC is presented in Figure 32.

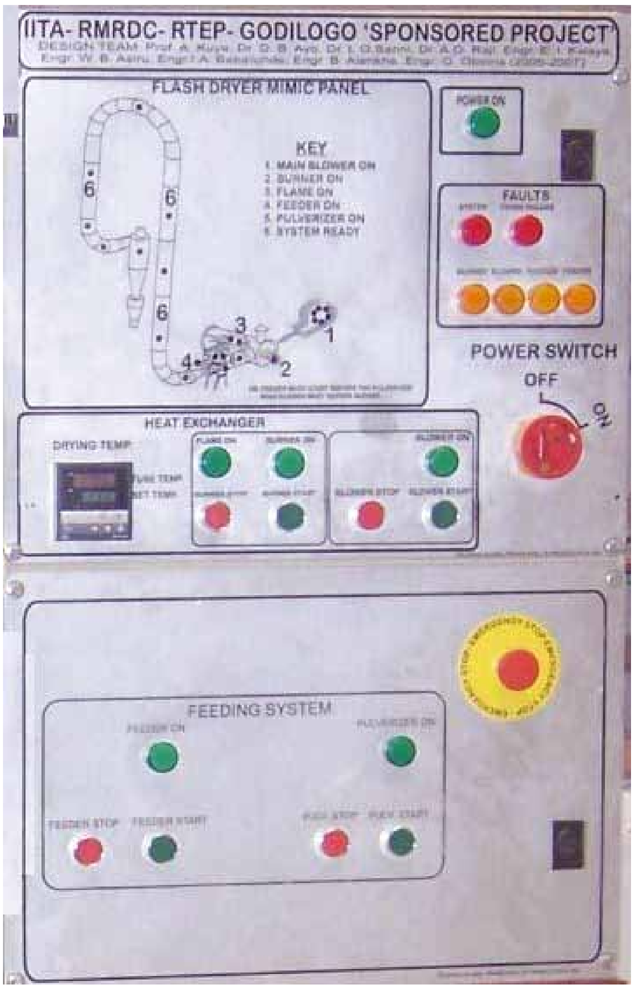

Figure 32. Motor Control Center.

Phase failure and phase imbalance protection

The Murphy range of voltage relays UVR/OVR500 (Figure 33) was used in building the MCC. These relays provide monitoring of single or three-phase AC mains/generator supplies. Relay outputs give controlled signaling/tripping at customer-set voltage levels.

Each relay circuit includes a double pole change-over relay, configured to be energized at normal AC voltage; an LED to indicate the relay state; the LED lights up when the relay is energized (when AC voltage is healthy), and a front facia “set volts” adjustment control, for setting the under/over trip voltage. The under-voltage relay de-energizes if any of the phase to neutral input voltages fall below the “set volts” level. The relay does not energize (or the UVR LED light up) until all phase to neutral voltages are restored to above the set volts *plus* the (adjustable) differential voltage.

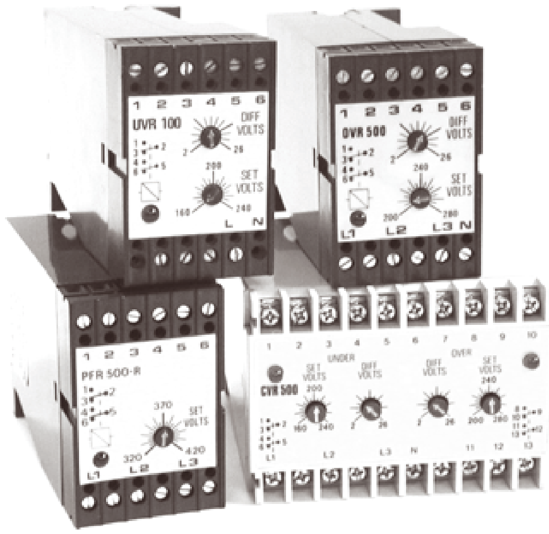

Figure 33. UVR/OVR500 voltage relays.

On Over-Voltage Relay (OVR) and Current Voltage Relay (CVR) units, the over-voltage relay de-energizes if any of the phase to neutral voltages rise above the “set volts” level. The relay does not energize (or the OVR LED light) until all the phase to neutral voltages return below the set voltage *minus* the differential voltage. The over-voltage relay also de-energizes on a total loss of supply.

On Phase Failure Relay (PFR) units, two phase voltages are compared with the third phase. The relay de-energizes if either phase to phase voltage falls below the set level. The relay does not energize until the phase to phase voltages rise above the set volts level *plus* the (fixed) differential voltage. On “R” option units, the relay energizes only if the correct phase sequence is connected.

Figure 34. REX-C100 Digital Temperature Controller

The Century Series were used because they are high performance controllers designed for maximum control performance at the most reasonable cost. These instruments are recognized for their solid reliability, ease-of-use, simplified menus and prompts, and easy key operations to change set points. The Century Series feature dual displays showing both the set point and the process value (orange/green LEDs). PID values can be easily obtained by auto-tuning the instruments at a touch of a button or they can be manually entered through an easy, touch key operation.

With the provision for presetting the operating temperature the flash tube temperature is monitored and regulated to provide consistent drying conditions through the controller. A maximum of two alarms are available on the Century Series. These alarms were programmed to be Temperature (Process, Deviation, or Band Alarms), Loop Break Alarm or Heater Break Alarm.

Heater break alarm (HBA)

The HBA detects failures in the oil burner output and monitors the load via an external current transformer. The current transformer sends an alert signal when the load current falls below a threshold value set in the MCC.

Loop break alarm (LBA)

The LBA monitors and protects an entire temperature control system. It can detect heater breaks, thermocouple or RTD failure, short circuits, or the failure of operating devices such as mechanical relays, mercury relays, and SSRs.

Heat/cool PID action

The use of Heat/Cool PID action with dead-band function achieves energy savings in the heat exchanger. It is also used with an overlap function to provide a stabilized temperature for a controlled flash tube (drying chamber) with a large time constant. The C100 was used because it is economical, easy-to-use, and designed to handle the rigors of industrial applications with minimal maintenance.

The PV derivative PID of the C100 is shown in Figure 35. Figures 36 and 37 show the burner and the block diagram of the motor control center.

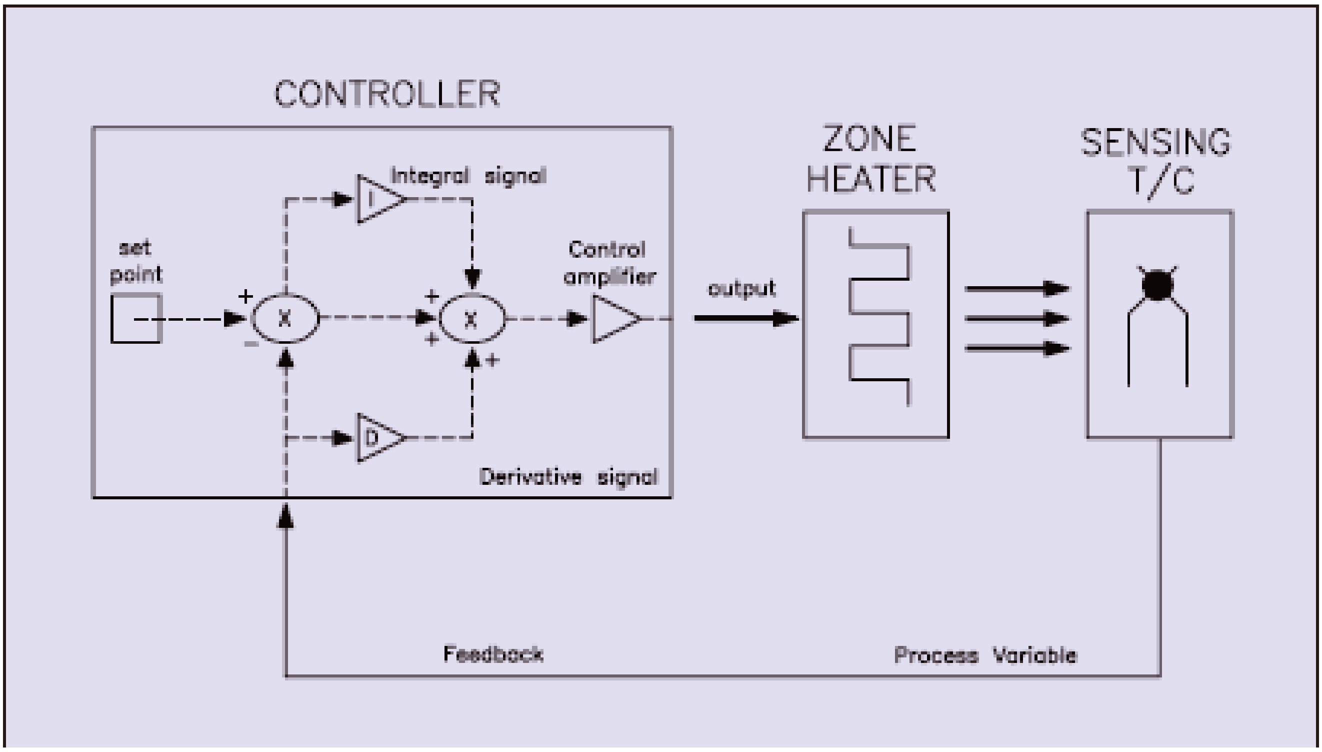

Figure 35. PV derivative PID of REX C100.

Figure 36. Light oil burner.

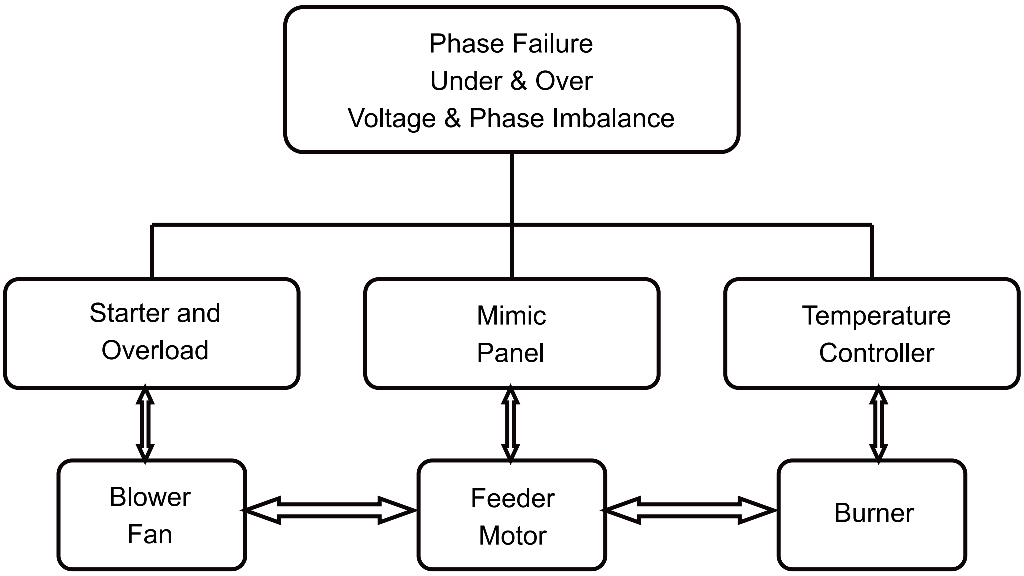

Figure 37. Block diagram of the MCC.

Working process

Cold air is sucked in through a filter by the blower and blown through the hot-air generator. The burner fire heats up the fire tube. The clean air entering the hot-air generator flows over the fire tube in two passes and the heat generated is absorbed in the air stream. The heated air is introduced into the flash ducting through a venturi system. The material to be dried is also introduced into the venturi through a feeding unit. This unit is composed of a grater mechanism which breaks up the cake lump and passes the pulverized material into the

screw auger metering system that transfers it to the venturi throat. The material encounters the hot air at the throat of the venturi and is mixed and then swept upwards along the drying duct as particulates.

During the short resident travel in the duct, the moisture in the product is removed by the hot air, leading to a decrease in the temperature of the air and an increase in the relative humidity. The dried particulates are then passed through a cyclone unit where they are separated from the moist air. The product is collected in the settling unit below the cyclone and discharged in batches before being milled into powder.

Operation process

1. Ensure there is enough diesel in the tank to supply the burner during the entire drying period.
2. Inspect the blower fan and clean the attached air filter unit when it is dirty or blocked.
3. On the control panel, switch on the main power.
4. Switch on the fan motor and allow it to run for 1–2 minutes to blow up settled powder in the duct. This is necessary when another product is to be processed.
5. Switch on the burner.
6. Allow the temperature in the tube to rise to 120 ºC.
7. Switch on the screw feeder unit and feed the processed cake into the hopper.
8. Allow the powder to settle and be discharged every 10 minutes.
9. Package in 50 kg sacks.
10. Store in a properly ventilated storehouse.

Standards and Test Results

Introduction

The fabricated flash dryer was installed at the Godilogo Farms Nigeria Ltd at Bebi, Obanliku LGA, Cross River State and tested under industrial conditions. The results obtained are presented in this section. Also presented is the Nigerian Standard for cassava flour. It should be noted that only a portion of the Standard is included. The reader can refer to Sanni et al. (2005) for further details.

Testing of the Flash Dryer

Various tests were conducted on the component basis. These included the heat exchanger unit, fuel consumption efficiency, feed mechanism and the throughput. Other tests on the flash dryer included tests to establish an optimum operating temperature. Each of the test results is discussed.

Heat exchanger unit

The heat exchanger, otherwise called a hot-air generator, comprises the burner, fire tube, hot-air deflecting chamber, the flue gas exhaust (chimney), and the lagging material. Outside the heat exchanger is the centrifugal fan/blower which transports the generated hot air to the drying tube via the venturi.

A welding test was conducted on the heat exchanger in view of its importance. However, since X-ray test equipment was not available, a simple burn-in test was carried out. This involve stressing the heat exchanger parts and the use of a sledge hammer to hit the welded joint and ensure the proper joining of members to avoid an explosion from the fire tube and hot-air deflectors. A proper x-ray test is recommended for future testing to ascertain its reliability.

Fuel consumption test

The burner was subjected to evaluation by operating the heat exchanger at no-load and on-load. The fuel consumption rate was assessed by measuring the fuel level in the tank against the time. The result obtained during the tests showed that an average of 13 l/hour of fuel was consumed by the dryer during operations. The functional relationship of the fuel consumption (FC, liters) obtained by statistical analysis of the data taken with time (t, mins) was obtained as

$FC = 0.002t^3 - 0.0565t^2 + 0.6976t + 0.0463$ ($R^2 = 0.9952$)

During the test, the burner was calibrated and the condition was noted under which an optimal flame was produced in the fire tube.

Feed mechanism

As the objective was the adequate pulverization and conveyance of the designed quantity of wet cake, the feeder was tested by loading the dewatered cake and operating the machine until a measured quantity of the feed was exhausted; the time was noted. The test was repeated at varying speeds and the results obtained were analyzed to enable the conclusion to be drawn on the designed feed rate.

The designed 820 kg/h at an optimum operating speed of 75 rpm was not achieved. A maximum feed rate was obtained of 702 kg/h at the maximum speed of 72 rpm obtainable from the drive mechanism installed. The trend of variation of the flow rate (FR) (kg/h) against speed (s, rpm) was obtained as
$FR = -0.003s^3 + 0.3279s^2 + 0.1311s + 113.81$ ($R^2 = 0.9907$).

Temperature evaluation

The flash dryer has an integrated MCC incorporated with various electrical/electronic devices that enabled the auto-sensing operation of the plant according to the design. Thermal probes connected to the MCC were fitted at the HE exit/venturi inlet, and upstream of the venturi and along the drying tube. The operating temperature which is also a variable was pre-set to regulate the operation of the burner. This is expected to turn off when the temperature is within the preset ± 5 ºC. The temperature readings at the venturi throat just before the hot air mixes with the pulverized products are as presented in Figure 38. It can be observed that the temperature rose to 125 ºC from a cold start (for a preset temperature of 120 ºC) and thereafter started fluctuating around this temperature, rising and falling between 117 ºC and 125 ºC in response to the auto-shutting and starting of the burner.

After drying, the dryer cooling curve was also monitored and presented (Fig. 6.1). It took about 18 minutes to cool to below about 40 ºC, after which the rate of cooling was reduced considerably. This slow cooling rate is advantageous as it helps in fuel conservation when the dryer is to be operated within this period of being shut down. It would take less time to heat up to the preset temperature from a hot start. Further retention of heat could be achieved by lagging the flash tube with fiber glass.

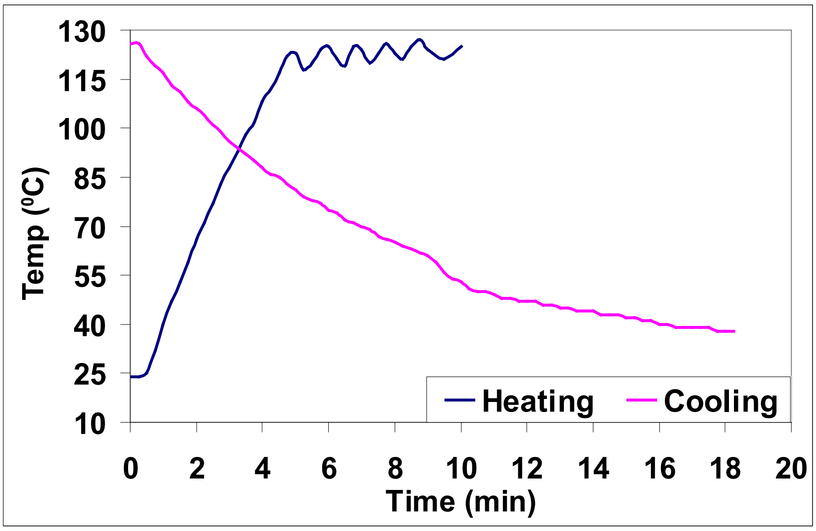

Figure 38. Temperature profile during the heating and cooling of the dryer.

Throughput

This is another important test to evaluate the input-output performance of the plant. The test involved measuring the quantity of dried flour obtained as a fraction of the material loaded. The moisture content of the material was then measured to ensure the quantity obtained represented the expected amount and that no material had been retained and was accumulating in the dryer. By design calculations, loading a feedstock having a moisture content of 45% (wb) and an input weight of 50 kg, the expected output by weight of the dried product if dried to a moisture content of 7% should be 31 kg. The results of the tests conducted with replications revealed that for this input weight, the final dried product weight obtained was 30 kg with final moisture content ranging between 5 and 6%. This indicated an excellent performance.

Proximate analysis and product color

Samples of the products were collected during the various tests described above on different occasions. These samples were analyzed for proximate composition, particle size distribution, and color. These were compared with the results for products from other dryers and against some available standards. The result is presented in Table 2.

The Hunter's L*a*b color analysis of the samples was carried out and compared with the results of a white paper to show the level of lightness of the flour. The results shown in Table 3 indicate higher lightness values (L) for the flour from the flash dryers than the reference value for a white paper, that is, 90.29 compared with 87.48. This shows that the flours appear brighter in color. This result is an indication of good quality flour not contaminated by smoke or burning from the body of the dryer that can often lead to discoloration in other types of dryers.

Table 4 lists the requirements for producing good quality cassava flour.

Table 2. Proximate analysis of the samples.

	% MC	% Ash	% Protein	Final visc.	Pasting temp.
Samples dried in existing dryers	9.41	1.32	0.34	240.50	75.25
Sample dried in the new dryer	5.67	1.41	0.52	127.33	76.90

Table 3. Color analysis of flour samples.

	L	a	b
White paper (Control)	87.48	2.83	–0.84
Samples dried in existing dryers	91.97	–0.42	16.69
Samples dried in the new dryer	90.29	0.13	17.95

L = lightness; a = degree of redness + to greenness –; b = degree of blueness – to yellowness +.

Table 4. Requirements for cassava flour.

S/N	Parameters	Requirement
1.	Max. moisture % (m/m)	10
2.	Max. crude fiber % (m/m)	2.0
3.	Max. sulphated ash (m/m) (on dry basis)	0.6
4.	Max. total acidity % (m/m)	1.0
5.	Max. hydrocyanic acid and its glucosides measured as hydrocyanic acid mg/kg (on dry basis)	10
6.	Min starch content (%)	65–70

Source: Sanni et al. (2005).

When tested by appropriate methods of sampling and examination, the product:

a. shall be totally free from pathogenic micro-organisms
b. the total aerobic count shall not exceed 10,000 (CFU)/g

it shall not contain any other poisonous extraneous, or deleterious substances in an amount which may represent a hazard to health.

Vibration and noise level

The vibration and noise levels were evaluated by comparing the operation of the new dryer against that of two existing dryers in the same factory. The vibration and the noise levels were found to be very low and within acceptable limits.

Nigerian standards for edible cassava flour

Cassava flour is classified into two categories as follows:

(1.) "Fine" cassava flour

This is cassava flour of which not less than 90% by weight shall pass easily through a sieve of 0.2 mm aperture size.

(2.) "Coarse" cassava flour

This is cassava flour of which not less than 90% by weight shall pass easily through a sieve of 0.4 mm aperture size.

Organoleptic properties: The color, taste, and odor of cassava flour shall be characteristic of the product.

Pesticide residue limits shall conform with values shown in Table 5. Table 6 shows the maximum limits for metallic contaminants.

Table 5. Maximum residue limits for pesticides.

Residue	Maximum level (mg/kg)
Pirimiphos methyl	0.10
Malathion	0.10
Hydrogen cyanide	0.05
Permethrin	2.0
Deltamethrin	2.0
Dichlorvos	2.0
Fenitrothion	10.0
Chlorpyrifus	10.0
Bromoethane	5.0
Hydrogen phosphide (Phosphine)	0.1

Metallic contaminants shall be in conformity with Table 6.5.

Table 6. Maximum limits for metallic contaminants.

Contaminants	Maximum level (mg/kg)
Arsenic	0.1
Copper	20.0
Lead	1.0
Mercury	0.1
Tin	15.0
Zinc	50.0
Iron	22.0

Cassava flour shall be stored in a dry, cool place on pallets.

Nigerian standards for composite flour

Composite flour is:

- the combination of wheat flour and one or more non-wheat flours from indigenous cereals, roots, tubers, legumes, or oilseeds, for the production of bread and other baked products;
- the combination of non-wheat flours from indigenous cereals, roots, or legumes for use in local recipes.

Levels of replacement of wheat flour with a single type of non-wheat flour in a composite flour shall be as shown in Table 7. Where more than one type of non-wheat flour is used, the sum of the individual components used shall not exceed the maximum level permitted for any one of the components. Table 8 shows the analytic properties of flours that can be used as composites.

Table 7. Percentage of permissible composite flours.

Type of flour	% wt of composite flour
Sorghum	10—20
Maize	10—25
Millet	10—20
Cassava flour	10—30
Cassava starch	10—30
Rice	10—30

Table 8. Analytical characteristics of flours for use in composite flours.

Type of flour	Parameters						
	% Moisture (max)	% Ash (max)	% Fiber (max)	% Fat (max)	% Protein (min)	pH (10% sol)	HCN (mg/kg) (max)
Wheat	13	0.65	2.5	1.2	8	6–7	-
Sorghum	12	1.2	1.5	3.0	8	6–7	-
Maize	12	0.4	0.8	1.0	8	6–7	-
Millet	12	1.0	2.0	4.0	7	6–7	-
Cassava flour	12	0.7	1.5		1	6–7	10
Cassava starch	12	0.1	-	-	0.5	6–7	10
Rice	12	0.3	0.2	0.25	5	6-7	-

All composite flour shall be free from any pathogenic microorganisms. The flour shall comply specifically with the microbial specifications:

Table 9. Microbial specifications for composite flour.

Organism	Max. cfu/kg sample
E. coli	Nil
Enterobacteria	Nil
Staph. aureus	Nil
Other coliforms	102
Mold	102
Yeast	102
Total count	104
Toxigenic molds	Nil

Nigerian standards for cassava starch

Food grade cassava starch is a white granular product that:

- is obtained by wet extraction process from mature cassava roots,
- satisfies the quality requirements as outlined in Tables 10 and 11. Full quality requirements are given by Sanni et al. (2005).

Particle size: Not less than 95% of the mass of cassava starch shall pass easily through a sieve of 100–140 microns or 0.1–0.12 mm mesh screen

Table 10. Analytical characteristics of cassava starch.

Analytical characteristics	Requirement
Total acidity	1.0% measured as lactic acid (max.)
pH	5–7
Hydrocyanic acid and its glucosides	10 mg/kg (max)
Starch content	95% (min.)
Moisture	12%. (max.)
Fiber	0.2%. (max.)
Sulphated ash	0.6%. (max.)
Viscosity or pasting properties	33–34 cSt
Insoluble ash	0.2% max.
Chloride	0.64 max.

Note: Every other starch that does not conform to the above table is classified as industrial starch.

Tables 11. Permissible levels of contaminants in cassava starch.

Contaminants	Maximum level permissible in mg/kg of dry matter
Sodium (Na)	74
Manganese (Mn)	12
Iron (Fe)	22
Copper (Cu)	4.3
Bromine (Br)	6.6
Zinc (Zn)	19
Molybdenum (Mo)	17
Aluminum (Al)	30
Oxalate	26
Lead	1

Source: Sanni et al. (2005).

Notation

A_1	Area of the hopper bottom surface, m^2
A_2	Area of the hopper top surface, m^2
C	Capacity, ft^3/h
C_p	Coefficient based on thermal property of air, KJ/kg.K
CPL	Specific heat of pure water, J/kg^oK
CPV	Specific heat of water vapor, J/kg^oK
Cs	Specific heat of dry solids, J/kg^oK
D_c	Cyclone diameter, m
D_2	Diameter of largest particle to be conveyed, m
E	Drive efficiency
f	Fluid frictional factor
F*b*	Hanger bearing factor
F*d*	Conveyor diameter factor
F*f*	Flight factor
F*m*	Material factor
F*o*	Overload factor
F*p*	Paddle factor
F_r	Feed rate, kg/h
G	Mass flow rate, kg/m^2-h
H	Height, m
h_c	Surface coefficient for convective heat transfer, kg/KJ.K
h_1	Height of hopper top section, m
h_2	Height of hopper bottom section, m
H_i	Initial enthalpy of air, kg/KJ
H_o	Initial enthalpy of air, kg/KJ
ID	Internal diameter, inches
L	Total length of conveyor, ft
L_H	Length of heat exchanger, m
Ma	Mass of air, kg
Ms	Mass of dry solids, kg
N	Operating speed, rpm
P_{bends}	Pressure drop across bend into the bottom of the flash tube, m
$P_{cyclone}$	Pressure drop across cyclone separator, m
P_f	Power to overcome friction, hp
$P_{flash\ tube}$	Pressure drop across flash tube, m

$P_{heat\ exchanger}$	Pressure drop across heat exchanger, m
P_m	Power to transport materials, hp
P_{throat}	Pressure drop across venturi throat, m
$P_{tube\ bends}$	Pressure drop across bends up-stream of cyclone separator, m
P	Total pressure drop, m
P_T	Total power, hp
Q	Total heat transferred, J/s
q	Heat transfer by convection, W
Q	Volumetric flow rate, m^3/sec
R	Duct bending radius, m
Re	Reynolds number
r_i	Outside radius of the inside tube (m, ins)
r_o	Inside radius of the outside tube (m, ins)
t_f	Fluid film temperature, ºC
Tf	Temperature of feed, ºC
Tp	Temperature of solid, ºC
t_r	Resident time, min
t_s	Surface temperature, ºC
Tv	Vaporization temperature, ºC
TVB	Final vapor temperature, ºC
v	Volumetric flow rate, gal/min
V	Flow velocity, ft/sec
V_a	Volume of air, m^3
V_{actual}	Actual carrying velocity, m/sec
V_f	Volumetric flow rate, m^3/h
V_m	Minimum carrying velocity, m/sec
V_s	Volume of solid, m^3
V_t	Total volume, m^3
W	Weight of material, lb/ft^3
Xf	Moisture content of feed, kg moisture/kg dry solid
Xp	Moisture content of products, kg moisture/kg dry solid
l	Latent heat of vaporization, J/kg
ϱ_a	Density of air, kg/m^3
ρ_b	Bulk density of mash, kg/m^3
DH	Change in enthalpy of air, kg/KJ
DP	Total pressure drop

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Annex A

Note: All the tables presented in this Annex were obtained from Martin Screw Conveyor Components (2006). The reader should consult this document for the full tables; only those used for this work are included here.

Table A1. Material classification code chart.

Major class	Material characteristics included		Code designation
Density	Bulk Density, Loose		Actual Lbs/PC
Size	Very Fine	No. 200 Sieve (.0029") And Under No. 100 Sieve (.0059") And Under No. 40 Sieve (.016") And Under	A_{200} A_{100} A_{40}
	Fine	No. 6 Sieve (.132") And Under	B_6
	Granular	½" And Under (6 Sieve to ½") 3" And Under (½ to 3") 7" And Under (3" to 7")	$C_{½}$ D_3 D_7
	Lumpy	16" And Under (0" to 16") Over 16" To Be Specified X=Actual Maximum Size	D_{16} D_X
	Irregular	Stringy, Fibrous, Cylindrical, Slabs, Etc.	E
Flowability	Very Free Flowing Free Flowing Average Flowability Sluggish		1 2 3 4
Abrasiveness	Mildly Abrasive Moderately Abrasive Extremely Abrasive		5 6 7
Miscellaneous Properties Or Hazards	Builds Up and Hardens Generates Static Electricity Decomposes — Deteriorates in Storage Flammability Becomes Plastic or Tends to Soften Very Dusty Aerates and Becomes a Fluid Explosiveness Stickiness — Adhesion Contaminable, Affecting Use Degradable, Affecting Use Gives Off Harmful or Toxic Gas or Fumes Highly Corrosive Mildly Corrosive Hygroscopic Interlocks, Mats or Agglomerates Oils Present Packs Under Pressure Very Light and Fluffy — May Be Windswept Elevated Temperature		F G H J K L M N O P Q R S T U V W X Y Z

Table A2. Material characteristics.

Material	Weight lb. per cu. ft.	Material code	Intermediate bearing selection	Component series	Mat'l factor Fm	Trough loading
Silicon Dioxide (See Quartz)	—	—	—	—	—	—
Silica, Flour	80	A40-46	H	2	1.5	30B
Silica Gel + 1⁄2″ - 3″	45	D3-37HKQU	H	3	2.0	15
Slag, Blast Furnace Crushed	130-180	D3-37Y	H	3	2.4	15
Slag, Furnace Granular, Dry	60-65	C1⁄2-37	H	3	2.2	15
Slate, Crushed, — 1⁄2″	80-90	C1⁄2-36	H	2	2.0	30B
Slate, Ground, — 1⁄8″	82-85	B6-36	H	2	1.6	30B
Sludge, Sewage, Dried	40-50	E-47TW	H	3	.8	15
Sludge, Sewage, Dry Ground	45-55	B-46S	H	2	.8	30B
Soap, Beads or Granules	15-35	B6-35Q	L-S-B	1	.6	30A
Soap, Chips	15-25	C1⁄2-35Q	L-S-B	1	.6	30A
Soap Detergent	15-50	B6-35FQ	L-S-B	1	.8	30A
Soap, Flakes	5-15	B6-35QXY	L-S-B	1	.6	30A
Soap, Powder	20-25	B6-25X	L-S-B	1	.9	45
Soapstone, Talc, Fine	40-50	A200-45XY	L-S-B	1	2.0	30A
Soda Ash, Heavy	55-65	B6-36	H	2	2.0	30B
Soda Ash, Light	20-35	A40-36Y	H	2	1.6	30B
Sodium Aluminate, Ground	72	B6-36	H	2	1.0	30B
Sodium Aluminum Fluoride (See Kryolite)	—	—	—	—	—	—
Sodium Aluminum Sulphate*	75	A100-36	H	2	1.0	30B
Sodium Bentonite (See Bentonite)	—	—	—	—	—	—
Sodium Bicarbonate (See Baking Soda)	—	—	—	—	—	—
Sodium Chloride (See Salt)	—	—	—	—	—	—
Sodium Carbonate (See Soda Ash)	—	—	—	—	—	—
Sodium Hydrate (See Caustic Soda)	—	—	—	—	—	—
Sodium Hydroxide (See Caustic Soda)	—	—	—	—	—	—
Sodium Borate (See Borax)	—	—	—	—	—	—
Sodium Nitrate	70-80	D3-25NS	L-S	2	1.2	30A
Sodium Phosphate	50-60	A-35	L-S	1	.9	30A
Sodium Sulfate (See Salt Cake)	—	—	—	—	—	—
Sodium Sulfite	96	B6-46X	H	2	1.5	30B
Sorghum, Seed (See Kafir or Milo)	—	—	—	—	—	—
Soybean, Cake	40-43	D3-35W	L-S-B	2	1.0	30A
Soybean, Cracked	30-40	C1⁄2-36NW	H	2	.5	30B
Soybean, Flake, Raw	18-25	C1⁄2-35Y	L-S-B	1	.8	30A
Soybean, Flour	27-30	A40-35MN	L-S-B	1	.8	30A
Soybean Meal, Cold	40	B6-35	L-S-B	1	.5	30A
Soybean Meal, Hot	40	B6-35T	L-S	2	.5	30A
Soybeans, Whole	45-50	C1⁄2-26NW	H	2	1.0	30B
Starch	25-50	A40-15M	L-S-B	1	1.0	45
Steel Turnings, Crushed	100-150	D3-46WV	H	3	3.0	30B
Sugar Beet, Pulp, Dry	12-15	C1⁄2-26	H	2	.9	30B
Sugar Beet, Pulp, Wet	25-45	C1⁄2-35X	L-S-B	1	1.2	30A
Sugar, Refined, Granulated Dry	50-55	B6-35PU	S	1	1.0-1.2	30A
Sugar, Refined, Granulated Wet	55-65	C1⁄2-35X	S	1	1.4-2.0	30A
Sugar, Powdered	50-60	A100-35PX	S	1	.8	30A
Sugar, Raw	55-65	B6-35PX	S	1	1.5	30A
Sulphur, Crushed — 1⁄2″	50-60	C1⁄2-35N	L-S	1	.8	30A
Sulphur, Lumpy, — 3″	80-85	D3-35N	L-S	2	.8	30A
Sulphur, Powdered	50-60	A40-35MN	L-S	1	.6	30A
Sunflower Seed	19-38	C1⁄2-15	L-S-B	1	.5	45
Talcum, — 1⁄2″	80-90	C1⁄2-36	H	2	.9	30B
Talcum Powder	50-60	A200-36M	H	2	.8	30B
Tanbark, Ground*	55	B6-45	L-S-B	1	.7	30A
Timothy Seed	36	B6-35NY	L-S-B	1	.6	30A
Titanium Dioxide (See Ilmenite Ore)	—	—	—	—	—	—

Table A3. Hanger bearing selection.

Bearing Component Groups	Bearing Typos	Recommended Coupling Shaft Material Δ	Max. Recommended Operating Temperature	F_b
B	Ball	Standard	180°	1.0
L	Bronze	Standard	300°	
S	Martin Bronze* Graphite Bronze Oil Impreg. Bronze Oil Impreg. Wood Nylatron Nylon Teflon UHMW Melamine (MCB) Urethane	Standard Standard Standard Standard Standard Standard Standard Standard Standard Standard	850°F 500°F 200°F 160°F 250°F 160°F 250°F 225°F 250°F 200°F	2.0
H	Martin Hard iron*	Hardened	500°F	3.4
	Hard iron Hard Surfaced Stellite ceramic	Hardened Hardened or Special Special Special	500°F 500°F 500°F 1,000°F	4.4

*Sintered Metal. Self lubricating.

Δ OTHER TYPES OF COUPLING SHAFT MATERIALS
Various alloys, stainless steel and other types of shafting can be furnished as required.

Table A4. Capacity table horizontal screw conveyors.

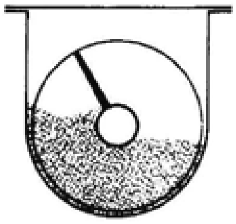
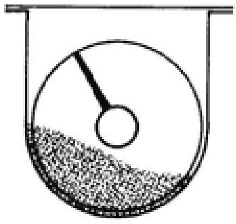
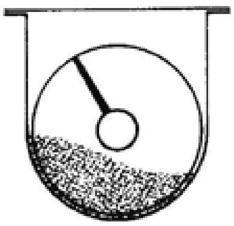
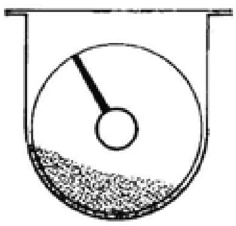
Trough Loading		Screw Dia. Inch	Capacity Cubic Feet per Hour (Full Pitch)		Max. RPM
			At one RPM	At max RPM	
45%		4	0.62	114	184
		6	2.23	368	165
		9	8.20	1270	155
		10	11.40	1710	150
		12	19.40	2820	145
		14	31.20	4370	140
		16	46.70	6060	130
		18	67.60	8120	120
		20	93.70	10300	110
		24	164.00	16400	100
		30	323.00	29070	90
30% A			0.41	53	130
		6	1.49	180	120
		9	5.45	545	100
		10	7.57	720	95
		12	12.90	1160	90
		14	20.80	1770	85
		16	31.20	2500	80
		18	45.00	3380	75
		20	62.80	4370	70
		24	109.00	7100	65
		30	216.00	12960	60
30% B			0.41	29	72
		6	1.49	90	60
		9	5.45	300	55
		10	7.60	418	55
		12	12.90	645	50
		14	20.80	1040	50
		16	31.20	1400	45
		18	45.00	2025	45
		20	62.80	2500	40
		24	109.00	4360	40
		30	216.00	7560	35
15%			0.21	15	72
		6	0.75	45	60
		9	2.72	150	55
		10	3.80	210	55
		12	6.40	325	50
		14	10.40	520	50
		16	15.60	700	45
		18	22.50	1010	45
		20	31.20	1250	40
		24	54.60	2180	40
		30	108.00	3780	35

Table A5. Conveyor diameter factor, F_d.

Screw Diameter Inches	Factor Fd
4	12.0
6	18.0
9	31.0
10	37.0
12	55.0
14	78.0
16	106.0
18	135.0
20	165.0
24	235.0
30	300.0

Table A6. Hanger bearing factor F_b.

Bearing Type		Hanger Bearing Factor Fb
B	Ball	1.0
L	Martin Bronze	2.0
S	*Graphite Bronze *Melamine *Oil Impreg. Bronze *Oil Impreg. Wood *Nylatron *Nylon *Teflon *UHMW *Urethane	2.0
	*Martin Hard Iron	3.4
H	*Hard Surfaced *Stellite * Ceramic	4.4

Non lubricated bearings, or bearings not additionally lubricated.

Table A7. Flight factor, F_f

Flight Type	F_f Factor for Percent Conveyor Loading			
	15%	30%	45%	95%
Standard	1.0	1.0	1.0	1.0
Cut Flight	1.10	1.15	1.20	1.3
Cut & Folded Flight Ribbon Flight	N.R.*	1.50	1.70	2.20
	1.05	1.14	1.20	—

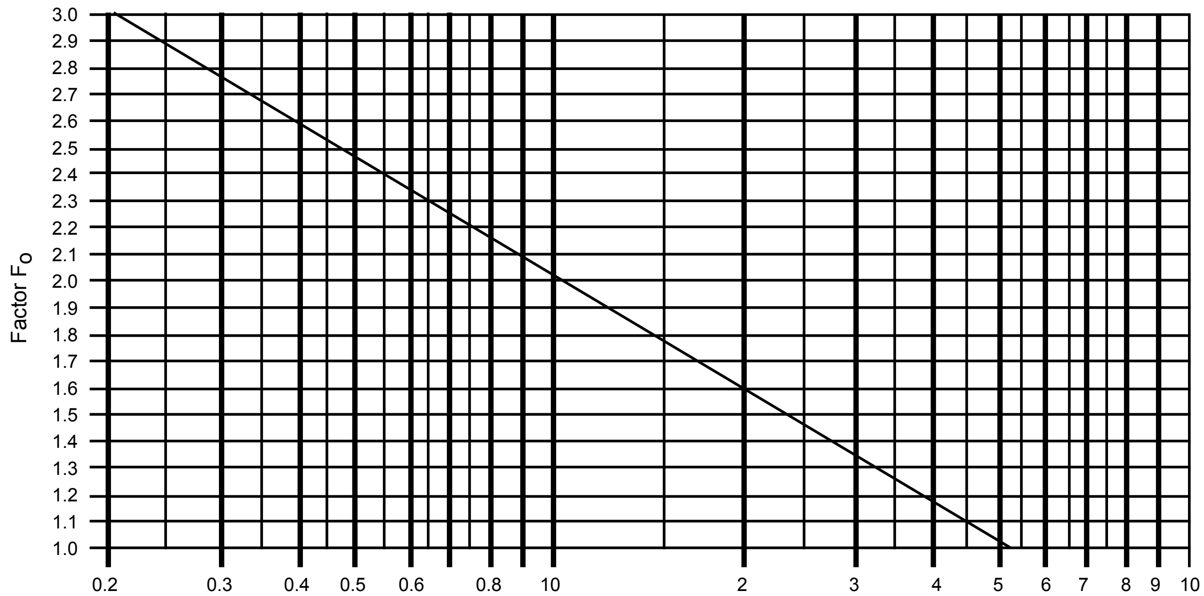
*Not Recommended

Table A8. Paddle factor F_p.

Standard Paddles per Pitch, Paddles Set at 45° Reverse Pitch

Number of Paddles per Pitch	0	1	2	3	4
Paddle Factor — F_p	1.0	1.29	1.58	1.87	2.16

Table A9. F_o — overload factor.



Horsepower $HP_f + HP_m$

For values of $HP_f + HP_m$ greater than *5.2, Fw_o* is 1.0

Trace the value of ($HP_f + HP_m$) vertically to the diagonal line, then across to the left where the F_o value is listed.

Table A10. q drive efficiency factor.

Screw Drive or Shaft Mount w/ V-Belt Drive	0.88
V-Belt to Helical Gear and Coupling	0.87
Gearmotor w/ Coupling	0.95
Gearmotor w/ Chain Drive	0.87
Worm Gear	Consult manufacturer

Annex B

Bill of materials for the flash dryer design.

S/N	Material description	Qty	Unit
1	2440 mm × 1220 mm by 1.5 mm thick stainless steel plate (AISI 304)	20	Sheets
2	2440 mm × 1220 mm by 3 mm thick stainless steel plate (AISI 304)	2	Sheets
3	2420 mm × 1220 mm by 5 mm thick stainless steel plate (AISI 304)	2	Sheets
4	2440 mm × 1220 mm by 5 mm thick mild steel plate	8	Sheets
5	2440 mm × 1220 mm by 10 mm thick mild steel plate	2	Sheets
6	2440 mm × 1220 mm by 2 mm thick mild steel plate	4	Sheets
7	200 mm diameter × 250 mm long cast aluminum grating drum / pulverizer drum	1	No.
8	75 mm diameter × 3000 mm long stainless steel pipe	1	No.
9	50 mm diameter × 3000 mm long stainless steel rod	1	No.
10	2440 mm × 1220 mm ×1 mm thick galvanized steel plate	2	Sheets
11	75 mm × 75 mm × 4880 mm long × 5 mm thick angle bar	2	Lengths
12	50 mm × 50 mm × 4880 mm long × by 5 mm thick angle bar	1	Length
13	100 mm diameter × 5 mm thick mild steel sprockets	3	No.
14	125 mm diameter × 5 mm thick sprocket	1	No.
15	200 mm diameter × 5 mm thick sprocket	1	No.
16	Roller chain (ISO Chain No 04B-1)	3	No.
17	915 mm × 610 mm × 4 mm thick cork gasket material	2	Rolls
18	Fiber glass 100 mm × 200 mm × 50 mm thick	4	Sheets
19	2000 mm long × 125 mm wide × 6 mm thick canvas belt	1	No.
20	75 mm diameter × 4000 mm long mild steel chimney pipe	1	No.
21	Gauge 12 stainless electrode	5	Packets
22	Gauge 10 & 12 mild steel electrode	20	10 packets each
23	Hacksaw blade	2	packets
24	150 mm diameter disc & grinding discs	40	20 pieces each
25	0–50 bar Pressure Gauge	2	No.
26	0– 00 0C (degree Celsius) temperature gauge	2	No.
27	22M bolts & nuts × 25 mm	100	Pieces
28	17M bolts & nuts × 50 mm	100	Pieces
29	3.5kW Centrifugal Blower	1	No.
30	2 hp variable speed (50–150 rpm) geared motor	1	No.
31	Burner (type: B26 light oil burner)	1	No.
32	75 cm × 450 mm Motor Control Center MCC (Panel Box)	1	No
33	25 amps contactor with overload switch	7	Set
34	100 amps contactor (main switch)	1	No.
35	20 amps three-phase fuse module	1	No.
36	Start/Stop switch (type, Telemechanique)	14	No.
37	MCC pilot indicating Lamps	8	N.
38	Light emitting diode (LED), white & red colors	30	10 pieces each
39	Phase-failure module (type SIEMENS Digital Phase Failure)	1	Set
40	Cables 1 mm, 2.5 mm, 4 mm, 6 mm,10 mm, and 16 mm	6	1 roll each
41	MCC panel cooling fan	1	no